Action priming is linked to visual perception in continuous flash suppression

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Visual prime stimuli can affect the processing of following target stimuli even if their visibility is reduced due to visual masking. Prime visibility depends on the stimulus parameters of the prime and those of the mask. Here we explored the effects of prime stimuli and modulated their visibility by continuous flash suppression (CFS). CFS reduces the visibility of a stimulus presented to one eye by simultaneously presenting a series of high-contrast masking stimuli to the other eye. We manipulated the strength of CFS effects on perception and examined how action priming effects of the masked stimuli varied under the same conditions. Prime visibility was modulated by the contrast of the primes (Experiments 1 and 2), the contrast of the masks (Experiments 2 and 3), and by the stimulus onset asynchrony between prime and target stimuli (all experiments). Surprisingly, action priming effects were modulated by these experimental variables in a parallel way. In addition, individual differences between participants in prime visibility correlated with individual differences in action priming. Our findings suggest that action priming and prime perception depend in similar ways on prime contrast, mask contrast, stimulus onset asynchrony, and individual dispositions in CFS. These findings distinguish CFS from other perceptual suppression techniques, such as backward masking, that allow reducing prime visibility without parallel effects on action priming. Our results corroborate the view that CFS interferes with visual processing at early stages in the cortical hierarchy with similar effects on later processing for perception and action.

Introduction

A widely shared perspective of the cortical processing of visual stimuli assumes a distinction between processes that entail stimulus awareness and processes that occur independent from stimulus awareness (e.g., Dehaene & Changeux, 2011; Goodale & Milner, 1992; Lamme, 2006; Neumann, 1990). According to a classical proposal, the processing of a visual stimulus occurs along a ventral vision-for-perception stream, and a separable dorsal vision-for-action stream (Goodale & Milner, 1992; Milner & Goodale, 2008). Other theories distinguish between early networks that operate without eliciting conscious awareness of the stimulus and later networks that have the potential to produce conscious stimulus perception (Dehaene & Changeux, 2011; Lamme, 2006).

This broad distinction is supported by behavioral data indicating that the perceptual reports of stimuli can be dissociated from their effects on speeded motor responses (e.g., Ansorge, Klotz, & Neumann, 1998; Breitmeyer, Öğmen, & Chen, 2004; Mattler & Fendrich, 2007; Neumann & Klotz, 1994; Schmidt, 2002; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003) or other speeded cognitive operations (e.g., Lau & Passingham, 2007; Mattler, 2003). For instance, Vorberg et al. (2003) presented small left- or right-pointing arrows as primes followed by larger left- or right-pointing arrows, which were utilized as backward metacontrast masks for the primes. The masks served as targets in a speeded choice response task, where participants responded to the direction of the target arrows with left- and right-hand responses, respectively. In a prime discrimination task, however, participants attended to the smaller prime arrows and indicated their direction with left- and right-hand responses without speed stress. In the choice response task, mean reaction time (RT) and choice error rate (ER) were reduced on trials on which prime and target were congruent (i.e., both arrows pointed to the same side) in comparison to trials on which prime and target were incongruent (i.e., prime and target pointed to different sides). In the prime discrimination task,

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however, participants could not discriminate the direction of the prime beyond chance level. Such dissociations between priming effects and perceptual performance in prime discrimination tasks support the distinction between stimulus processing with and without stimulus awareness.

Studies on priming effects in the absence of awareness are constrained by the specific techniques that are employed to reduce prime visibility (Breitmeyer, 2015; Kim & Blake, 2005). For example, backward masking reduces prime discrimination performance in a temporal window of up to about 150 ms depending on various spatial and temporal stimulus parameters (Breitmeyer & Öğmen, 2006). In consequence, priming studies that employed backward masking focused on a relatively short stimulus onset asynchrony (SOA) in which backward masks effectively reduce prime visibility. These studies typically found that priming effects increase monotonically as SOA increases, although SOA modulates prime visibility in various ways (Albrecht, Klapötke, & Mattler, 2010; Mattler, 2003, 2005; Mattler & Palmer, 2012; Vorberg et al., 2003). Vorberg et al. (2003), for instance, employed a 14-ms prime duration and varied the SOA of the prime and the target between 14 and 70 ms in steps of 14 ms, and prime discrimination performance was at chance level with every SOA. Priming effects, however, increased with increasing SOA. Albrecht et al. (2010) reported that subgroups of observers could markedly differ in how prime visibility varied with SOA, yet all observers showed similar monotonic increases in priming effects. Even when prime visibility is at high levels throughout the range of SOA levels of a study, priming effects show the same monotonic increase with SOA as under conditions of low prime visibility (Mattler & Palmer, 2012). Hence, a number of backward masking studies demonstrated priming independent of prime visibility with short SOAs. This typical finding with backward masking and short SOAs is depicted in Figure 1A. However, these studies cannot inform whether priming of unconscious stimuli is possible with longer SOAs because the strength of backward masking wanes with SOAs beyond 150 ms to the point where it is insufficient to eliminate the primes' visibility (Breitmeyer & Öğmen, 2006). Therefore, backward masking techniques are unsuitable for studying the processing of unconscious stimuli that affect the visual system for longer periods. However, studying stimulus processing independent of conscious perception with longer SOAs is of substantial theoretical value, because longer SOAs between prime and target potentially enable more elaborate types of unconscious processing.

A relatively recent addition to the toolkit of techniques for reducing the visibility of stimuli called continuous flash suppression (CFS) promises to shed light on the effects of stimuli that remain unconscious for longer time periods (Tsuchiya & Koch, 2005; Tsuchiya, Koch, Gilroy, & Blake, 2006; Yang, Brascamp, Kang, & Blake, 2014). CFS builds upon the phenomenon of binocular rivalry (BR), which occurs when incompatible visual stimuli reach to different eyes of an observer who may consequently perceive only one stimulus at the expense of the other (Blake, 1977; Levelt, 1965; Tong, Meng, & Blake, 2006; von Helmholtz, 1867). If the incompatible stimuli are similarly strong, perceptual dominance alternates between the two stimuli over time, with phases of mixed dominance. The strength of a stimulus and its perceptual predominance depend on stimulus properties such as luminance contrast, motion, size, or spatial frequency (Brascamp, Klink, & Levelt, 2015; Levelt, 1965). However, since in classical BR studies the rivalrous stimuli are static and similarly strong, researchers have limited control over which of the two stimuli will be initially perceived, and how the time course of perceptual suppression develops (Brascamp & Baker, 2013; Kim & Blake, 2005).

CFS, in contrast to BR, provides better experimental control over the observer's perceptual dynamic. In CFS, a high-contrast, dynamically changing mask stimulus is presented to one eye, while a low-contrast, usually smaller static stimulus is presented to the other eye. Observers initially perceive only the mask, and it can take several seconds before the weaker stimulus "breaks" suppression and is seen (Tsuchiya et al., 2006; Yamashiro et al., 2014). The robustness and strength of suppression vary considerably between different observers (Gayet & Stein, 2017; Kerr, Hesselmann, Räling, Wartenburger, & Sterzer, 2017; Yamashiro et al., 2014; Yang, Blake, & McDonald, 2010). Therefore, many CFS studies gradually reduced suppression by increasing the contrast of the suppressed stimulus and/or decreasing the contrast of the mask during an ongoing trial to allow all observers to eventually perceive the suppressed stimulus (Gayet, Van der Stigchel, & Paffen, 2014; Stein, Hebart, & Sterzer, 2011; Yang et al., 2014; Yang, Blake, & McDonald, 2010). Other studies adjusted the contrast of the stimuli to achieve more comparable suppression effects in different participants (Hesselmann, Hebart, & Malach, 2011; Hesselmann & Malach, 2011; Yuval-Greenberg & Heeger, 2013), or recorded the contrast increment necessary to break suppression as a dependent variable (Yang & Blake, 2012; Zhu, Drewes, & Melcher, 2016). Thus, contrast is a critical variable in BR and CFS that reliably modulates the strength of perceptual suppression.

CFS has been considered particularly promising for studying the processing of unconscious stimuli due to its strong and sustained perceptual suppression effects, allowing to present stimuli over more extended time periods during which participants have no

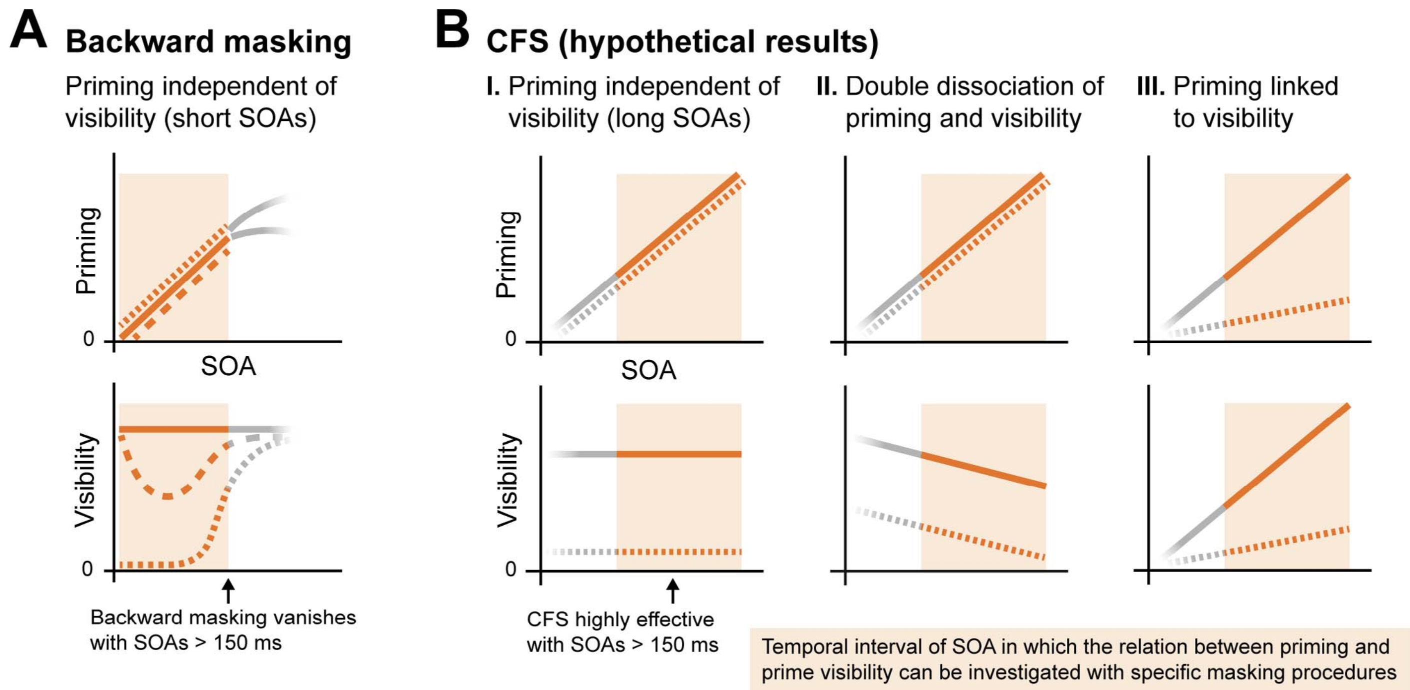

Figure 1. Illustration of the possible relationships between priming and prime visibility with short and long SOAs. (A) Studies that employed backward masking found priming effects that increase monotonically with increasing SOA independent of prime visibility. Depending on stimulus settings and individual differences between observers, visibility can remain at low (dotted lines), or high levels (solid lines), or it can follow a u-shaped function across SOA (dashed lines). With SOAs $>$ 150 ms, prime visibility is high, and it is difficult to examine dissociations between priming and prime visibility with backward masking. (B) CFS allows studying the relationship between priming and visibility with long SOAs. We depict three different possible outcomes of priming effects in conditions with low (dotted lines) and high prime visibility (solid lines). (Part I) Priming might increase with SOA irrespective of prime visibility, indicating independence between priming and visibility. (Part II) Priming might increase with SOA in conditions where visibility decreases. Such a double dissociation would constitute rather strong evidence for independence between priming and visibility. (Part III) Priming effects might change with experimental conditions in parallel to the changes in prime visibility. Such a pattern of results would suggest that priming is linked to prime visibility.

conscious access to the stimuli (Barbot & Kouider, 2012; Moors, Hesselmann, Wagemans, & van Ee, 2017). While initial CFS studies suggested intriguing high-level (semantic) priming effects without awareness of the primes, these studies were recently scrutinized for their methodological details, or proved difficult to replicate (for discussions see, e.g., Hesselmann, Darcy, Ludwig, & Sterzer, 2016; Hesselmann, Darcy, Sterzer, & Knops, 2015; Ludwig & Hesselmann, 2015; Moors et al., 2017). Thus, the extent to which stimulus processing during CFS could be independent of conscious perception is a matter of current debate (for reviews see, e.g., Hesselmann & Moors, 2015; Moors et al., 2017; Moors et al., 2019; Sterzer, Stein, Ludwig, Rothkirch, & Hesselmann, 2014; Yang et al., 2014).

Against the background of this ongoing debate, we set out to test if action priming is dissociable from visibility during CFS. We experimentally manipulated the visibility of primes and tested whether priming occurs independent of the level of visibility, as typically demonstrated in backward masking. Figure 1B schematically illustrates different possible outcomes on measures of priming effects and prime visibility. (a) Priming might increase with SOA irrespective of the prime's visibility. This pattern of results would indicate independence between priming and prime visibility (see Figure 1B, Part I). (b) Similarly, any evidence for a double dissociation between priming and prime visibility would point to independence of priming and visibility—for instance when priming increases with SOA while visibility decreases (see Figure 1B, Part II). (c) In contrast, priming effects and visibility could be modulated by the same experimental variables in similar ways. This pattern of results would indicate that priming effects are linked to prime visibility (see Figure 1B, Part III). To anticipate our results: Across three experiments, our data consistently fits with the last hypothetical outcome and thus argues for a link between priming and prime visibility under CFS conditions. More specifically, even with an SOA of 100 ms—which overlaps with the temporal interval of backward masking studies—priming effects correlate with prime visibility when CFS is used.

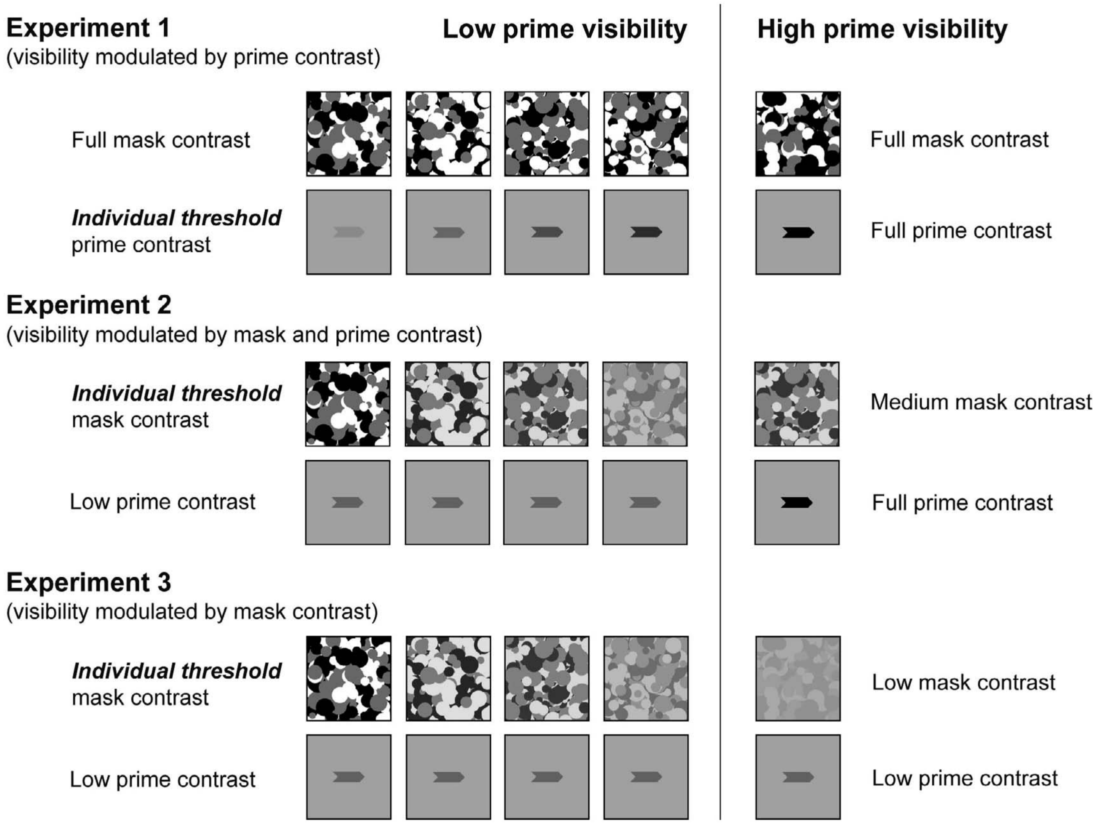

Figure 2. Manipulations of prime visibility in the different experiments of the present study. Experiment 1 used masks with maximal contrast and modulated prime visibility by adjusting prime contrast. Experiments 2 and 3 modulated prime visibility by adjusting the mask contrast. In all experiments, the low prime visibility condition was matched to the participants' individual discrimination thresholds.

Overview

We tested whether priming effects are independent of prime visibility—as found with backward masking studies—or whether priming effects increase with increasing prime visibility when CFS is used. By manipulating the relative contrast of primes and masks, we established two conditions of prime visibility within participants (see Figure 2): A high visibility condition, in which prime discriminability was well above chance level, and a low visibility condition, in which prime discriminability was adjusted for each participant to be close to the participant's prime discrimination threshold. In Experiment 1, we kept the mask contrast maximal and manipulated prime visibility by adjusting the contrast of the prime: In the low visibility condition, the prime's contrast was matched to each participant's prime discrimination threshold, while in the high visibility condition the prime's contrast was maximal. In Experiment 2, in the low visibility condition, we used a low-contrast prime and adjusted the contrast of the mask according to each participant's prime discrimination threshold. In the high visibility condition, we combined high-contrast primes with medium-contrast masks to ensure that all participants could reliably discriminate the primes because we found in Experiment 1 that prime visibility was very low in some participants when masks and primes had the maximal contrast. In Experiment 3, to examine whether differences in prime contrast alone caused the effect of prime visibility on priming effects, we used the same low-contrast primes in both visibility conditions. In the low visibility condition, we adjusted the contrast of the mask to the participant's discrimination threshold (as in Experiment 2), whereas in the high visibility condition, we used a low-contrast mask.

We expected a strong effect of our stimulus manipulations on the conscious perception of the primes, indexed by a poor prime discrimination performance in conditions with low prime visibility in all experiments. If priming during CFS is independent of conscious perception, the priming effect should not depend on prime visibility. Alternatively, if priming and conscious perception are not independent during CFS, increased prime visibility should lead to increased priming effects. In addition, we manipulated the SOA between the prime and the target, because priming effects usually increase with increasing SOA (Mattler, 2003; Mattler & Palmer, 2012; Vorberg et al., 2003). Moreover, an SOA manipulation can provide critical evidence of prime processing in the absence of awareness in terms of different time courses of priming effects and discrimination performance (Mattler, 2003; Schmidt & Vorberg, 2006; Vorberg et al., 2003). As outlined above, a major advantage of CFS compared with backward masking procedures consists in the possibility to achieve strong masking effects with long SOAs, which allows an investigation of priming effects of unconscious stimuli that can influence the system for a much longer time (cf. Figure 1). Specifically, we reasoned that prime discrimination performance could decrease with increasing SOA during CFS if the prime's perceptual representation would be overwritten more thoroughly by additional CFS masks before the perceptual discrimination is requested. In this case, priming effects might increase with increasing SOA while discriminability decreases (see Figure 1B, Part II). Different time courses of priming and prime discrimination would provide strong evidence for the view that conscious perception and priming rely on dissociable processes (Mattler, 2003; Schmidt & Vorberg, 2006; Vorberg et al., 2003).

Experiment 1: Prime visibility modulated by prime contrast

For the low visibility condition, we reduced the prime contrast to match each participant's discrimination threshold. For the high visibility condition, primes had the maximal contrast in all participants. In both visibility conditions, the masks had the maximal contrast in all participants. In all trials, participants attended to the targets as well as to the primes. Which of the stimuli was task-relevant was instructed on a trial-by-trial basis by the color of the fixation mark at target onset (see Figure 3). Whenever the fixation mark changed its color from green to blue, participants withheld the response to the target and instead discriminated the prime using the same response buttons. This task-switching procedure allowed us to measure priming as well as prime discriminability throughout the same experimental session while reducing interference between tasks and responses.

Method

Participants

Sixteen (12 female) students from the University of Goettingen with a mean age of 23.2 years ($SD = 4.20$ years) took part in three sessions in exchange for payment of €7 per hour. We decided to collect data from 16 participants because a prior study that used similar stimuli found mean priming effects of 53 ms with an SOA of 200 ms under conditions of partial prime awareness (Peremen & Lamy, 2014, pp. 8–10). Assuming the sample size and standard error reported in this prior study, our planned study with 16 participants yielded a power of 0.95 to detect significantly positive action priming effects between 24 to 82 ms (95% confidence interval [CI]). All participants had normal or fully corrected visual acuity. All experiments were conducted in accordance with the ethical standards of the American Psychological Association and the German Psychological Society. Informed consent was obtained in writing from all participants prior to participation.

Apparatus

Stimuli were presented on a ViewSonic PF817 22-in. color CRT monitor connected via VGA to an AMD Radeon HD6450 graphics card. Screen resolution was set to $1{,}024 \times 768$ pixels with a vertical refresh rate of 140 Hz. Viewing distance was fixed at 57 cm using a chinrest. Dichoptic stimuli were presented at different locations side by side on the same screen and viewed through a custom-built mirror stereoscope (OptoSigma Corp., Santa Ana, CA) that was mounted on the chinrest, allowing binocular fusion of the dichoptic stimuli. Participants responded with their left and right index fingers using the left and the right "control" keys on a standard USB keyboard. The experimental procedure was implemented in Presentation (Neurobehavioral Systems, Berkeley, CA) and run under Windows 7 on a Dell OptiPlex 990 PC with an Intel Core i7-2600 CPU and 16 GB of RAM.

Stimuli

To enable fusional vergence, the experimental stimuli were presented on a medium gray background (27.7 cd/m^2) within circular frames. Frames had a diameter of 9° and a 1/f noise pattern at the outer border of the frame which extended for about 2° towards the center where it smoothly blended into the neutral gray background (see Figure 3). Screen areas outside the frames were set to black (0.1 cd/m^2). A circular fixation mark with a diameter of 0.5° and a central black dot of 0.1° size was shown at the center of each of the frames in all phases of the experiments. Participants were instructed to fixate on the fixation mark at all times. Primes were smaller ($2.9° \times 1.0°$) left- or right-pointing arrows, presented to the participants' nondominant eye at fixation. Primes were always darker relative to the neutral gray background (Michelson contrast range 0.02 to 1.00). Targets were larger ($4.1° \times 1.4°$) left- or right-pointing arrows presented at a vertical center-to-

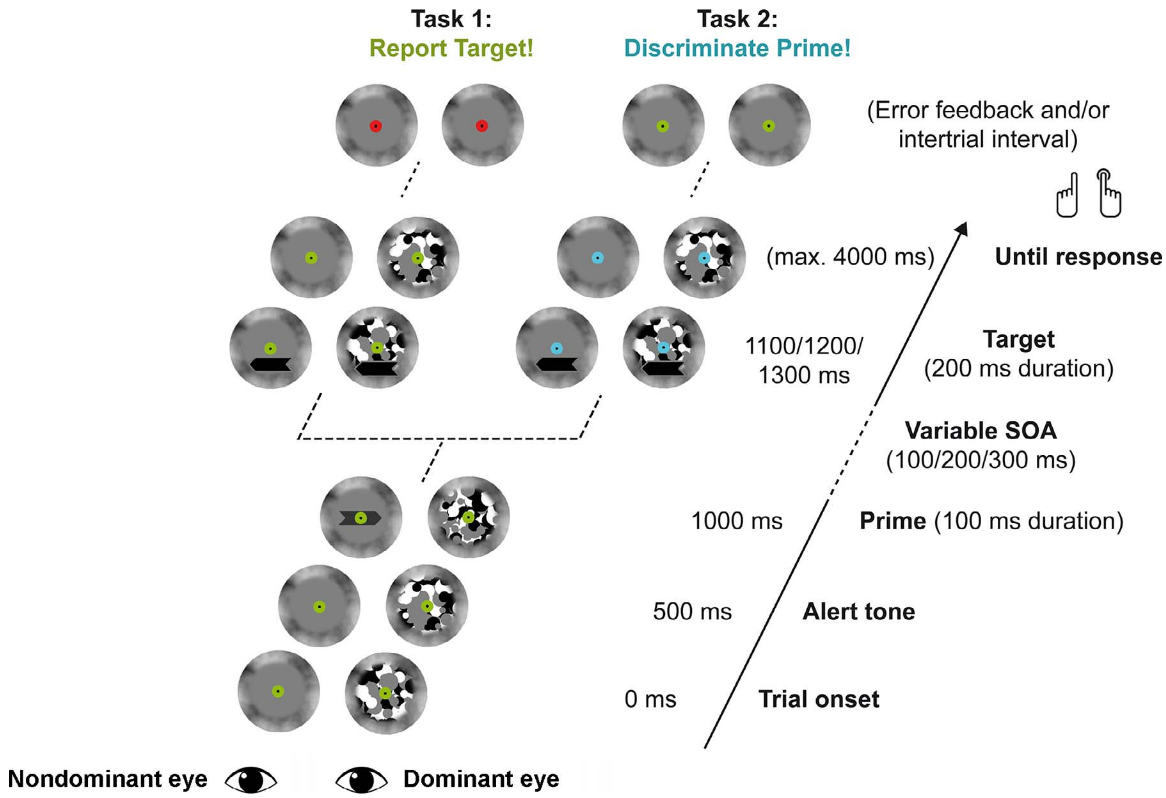

Figure 3. Schematic trial procedure in Experiments 1 and 2. In each session, two tasks were randomly intermixed across trials. Participants gave speeded responses to the eccentrically presented target arrow whenever the fixation mark maintained its green color (Task 1). Whenever the fixation mark changed its color from green to blue with target onset, participants gave nonspeeded reports of the centrally presented prime arrow (Task 2). In Experiment 3, stimuli and event timing were identical but the tasks were presented in separate sessions.

center eccentricity of ±1.7° above or below the fixation point to both eyes. Conscious perception of primes was suppressed by presenting a sequence of CFS masks to the participants' dominant eye at a rate of 10 Hz. CFS masks consisted of randomly positioned, overlapping, filled circles. Each circle element had a randomly chosen diameter between 0.5° to 1.7° and one of three possible luminance values (white, gray, or black, Michelson contrast of 1.00). The masks were randomly reshuffled in each trial.

Study procedures and protocols

Each participant came in for three sessions, which took place on separate days. Participants were prescreened for intact visual acuity of the left and the right eye and their ability to binocularly fuse the stimulus frames using the mirror stereoscope without experiencing any diplopic images. In the first session, we assessed the participants' sensory eye dominance. Afterwards, we determined the individual contrast threshold for the low prime visibility condition. In the remainder of the first session, participants completed a training session of 384 trials of the main experiment to familiarize them with the two tasks of the main experiment and to practice the switching between tasks (training data was not included in the analyses). In the second and third experimental session, we repeated the test for the individual threshold contrast. We always used the lowest of all obtained estimates for the low prime visibility condition. In each of the two sessions, participants completed 768 trials of the main experiment. The order of conditions and tasks was random. At the end of each session, participants were briefly interviewed about their subjective perceptions and strategies in the main experiment. At the end of the last session, participants were debriefed about the purpose of the study, paid and thanked for their participation. Each experimental session lasted between 90 and 110 min.

Eye dominance test

Sensory eye dominance was determined according to the method of Yang et al. (2010). The test consisted of 60 trials with CFS masks presented at 10 Hz. Masks were presented to the left eye in half of the trials, and to the right eye in the other half of trials, in a random order. In each trial, a left- or right-pointing target arrow appeared randomly above or below fixation with a temporally jittered onset time (800, 1000, or 1200 ms after the onset of the first CFS masks). The contrast of the target arrow increased linearly across a period of 5000 ms from 0.00 (identical with the neutral gray background) to 1.00 (black on neutral gray background). Simultaneously with the increase of target contrast, the mask contrast decreased in the same steps from 1.00 to 0.00. At the end of the trial, the mask was invisible and the target was presented in full contrast. Trials lasted for a maximum of 10 s. The participants' task was to report the target arrow's direction by button press as soon as they could recognize it. As the dominant eye, we defined the eye that resulted in the longer median suppression duration, when this eye was shown the CFS masks (Yang et al., 2010). Before commencing the eye dominance test, participants were introduced to the task using 10 demonstration trials.

Threshold contrast test

For each participant, we determined the lowest contrast level of the primes at which participants could discriminate primes slightly above chance using an adaptive staircase procedure (Watson & Pelli, 1983). The staircase estimated the stimulus contrast associated with a correct response probability of 0.6. The same prime arrows and masks were used as in the main experiment. To keep the threshold test time efficient, we used only the medium SOA of 200 ms. Participants were instructed to give nonspeeded reports of the direction of the prime arrow or make their best guess whenever they were unsure about its direction. Instead of presenting left- or right-oriented peripheral (target) arrows, we used an ambiguous arrow as a placeholder, generated by overlaying left- and right-target arrows. The contrast of primes was adaptively modulated on a trial-by-trial basis depending on the participants' response accuracy. Participants received the same error feedback as in the main experiment. Each participant completed 96 test trials, starting with the maximal contrast. Before commencing this threshold test, participants were introduced to the task using 12 demonstration trials.

Main experiment

The trial procedure in the main experiment is illustrated in Figure 3. Each trial started with the presentation of CFS masks at a rate of 10 Hz to the dominant eye. After 500 ms participants heard a brief warning tone (430 Hz, 150-ms duration). They were instructed to use this tone as temporal cue to refocus their attention on the imminent task-relevant stimuli (cf. Naccache, Blandin, & Dehaene, 2002). After 500 ms the prime was presented at fixation to the nondominant eye for 100 ms. Prime onset was synchronized with the onset of the 11th CFS mask in each trial. With a 100, 200, or 300 ms SOA, the target was presented to both eyes. The SOA of 100 ms links the present study to the literature on priming effects with backward masking paradigms, while SOAs of 200 and 300 ms were used to take advantage of CFS for the investigation of unconscious priming in a temporal range beyond what is possible with backward masking procedures. Targets were shown for 200 ms. The presentation of CFS masks continued until participants responded or until a maximum waiting period of 4000 ms following target onset expired.

Tasks

Participants performed two tasks, randomly intermixed across trials. The color of the fixation mark at target onset informed participants about the task-critical stimulus (cf. Figure 3): If the fixation mark remained green, participants reported the orientation of the left- or right-pointing target arrow in a speeded choice RT task by pressing response buttons with the left or right index finger. Whenever the fixation mark changed to blue, participants reported the prime arrow's direction in a prime discrimination task without speed stress using the same buttons. Participants were instructed to guess in case they could not see the prime's direction. In case of an incorrect response in either of the tasks, the trial stopped and the color of the fixation mark changed to red for 500 ms, serving as error feedback. If participants did not press a button within 4000 ms after target onset, the trial ended and the same error feedback was shown for 500 ms. Error feedback was followed by a jittered intertrial interval of 750, 1000, or 1250 ms, during which the green fixation mark within the empty frames was shown to both eyes. If participants responded correctly, no feedback was given and the next trial started after the intertrial interval. Participants did not receive any explicit feedback regarding response speed in either of the tasks. After blocks of 96 trials, participants were shown a pause screen informing them how many blocks they completed. They could use these pauses to briefly rest and continue with the experiment whenever they felt ready by pressing the "return" key. In each session, before starting the main experiment, participants completed a practice block of 64 trials (drawn randomly from all conditions) to get acquainted with the tasks and the stimuli before commencing the experiment.

Design

The main experiment featured a fully crossed within-participant design with the factors congruency (congruent vs. incongruent) of prime and target arrow direction, SOA (100 vs. 200 vs. 300 ms), and prime visibility (high vs. low). All combinations of prime and target directions and target positions were included with equal frequency in each session. Each of the 12 conditions per task was repeated 32 times per each session, resulting in 64 measurements per condition and task for each subject across both experimental sessions.

Data analysis

Performance in the speeded choice RT task was analyzed by repeated measures analyses of variance (ANOVAs) with Type II sums of squares to test for main effects and interactions of our experimental factors on the dependent variables mean RT of correct target responses, and ER (based on all trials). Mean RTs of each participant in each of the 12 conditions were determined based on trials in which the response was correct and RT was within ±2.5 *SD* around participants' mean correct RT in the respective condition. For an intuitive comparison of the influence of suppression on priming and conscious perception, we also report the net priming effect, i.e., mean RT on correct incongruent trials minus mean RT on correct congruent trials. For the statistical analysis of ERs, we applied an arc-sine transformation to the data but for the sake of interpretability we depict descriptive statistics of untransformed data.

Prime discrimination performance was analyzed with an analogous analysis of individual prime discriminability measures (d') based on signal detection theory (Green & Swets, 1966; Macmillan & Creelman, 2005). Trials in which participants did not respond as well as trials in which they responded within 300 ms after target onset were excluded from this analysis. The elimination of rapid responses serves the purpose to exclude any effects of unconscious motor activations of the prime that could inflate our measures of conscious perception of the prime (Vorberg et al., 2003). For each participant, a d' score was first calculated separately for trials with left- versus right-pointing target arrows, respectively, and then averaged across target arrow identities (Macmillan & Creelman, 2005; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2004). For computing d' despite floor or ceiling performance in certain participants and conditions, a log-linear correction was applied to the calculated hit and false alarm rates (Hautus, 1995).

When applicable, we report p values after applying the Greenhouse–Geisser (GG) correction (then denoted as p_{GG}) and the sphericity violation (GG-ε) but we always report uncorrected degrees of freedom for the sake of readability (Howell, 2010). In general, we assumed p values below an α of 0.05 as statistically significant. For post hoc pairwise comparisons, we applied a Bonferroni-corrected α probability. All data analyses were performed using R 3.4.2 (R Core Team, 2017) and ggplot2 (Wickham, 2016). Error bars in plots depict ±1 *SE* after correcting for between-participants variance (Loftus & Masson, 1994). Primary data of all experiments and R code to reproduce the statistical analyses are available through the Open Science Framework (https://osf.io/st7hg/).

Results

Figure 4 gives a summary of the group-level findings in Experiment 1: (A) shows performance in the choice RT task in terms of mean correct target RT and ER; (B) depicts the net priming effects (RT and ER in incongruent minus RT and ER in congruent trials, respectively) and (C) illustrates prime discriminability in the different experimental conditions.

Target RT

Across the entire sample we excluded 1,369 trials (11.1% of all trials) in which participants responded incorrectly. From the remaining trials, we excluded 303 trials (2.5% of all trials) as outliers. The main effect of congruency was significant, $F(1, 15) = 13.3$, $p = 0.002$, $\eta_p^2 = 0.47$, with shorter RTs on congruent than incongruent trials (467 vs. 550 ms, respectively). The main effect of SOA was significant, $F(2, 30) = 19.5$, $p_{GG} < 0.001$, $\eta_p^2 = 0.56$, $\varepsilon = 0.56$, with 533, 505, and 489 ms for 100, 200, and 300 ms SOA, respectively. The interaction of Congruency × Prime Visibility was significant, $F(1, 15) = 6.7$, $p = 0.021$, $\eta_p^2 = 0.31$, suggesting that priming effects were larger with high as compared with low prime visibility. No other effect was significant (all ps ≥ 0.114).

Target ER

The main effect of congruency was significant, $F(1, 15) = 14.8$, $p = 0.002$, $\eta_p^2 = 0.50$, with increased ER on incongruent as compared with congruent trials (15.8% vs. 6.5%). The main effect of SOA was significant, $F(2, 30) = 6.5$, $p_{GG} = 0.007$, $\eta_p^2 = 0.30$, $\varepsilon = 0.86$, with 9.3%, 11.6%, and 12.5% for 100, 200, and 300 ms SOA, respectively. No other effect was significant (all ps $\geq$ 0.172).

Prime discrimination performance

From all prime discrimination trials, we excluded 169 trials (1.4%) because participants either did not respond or their response was faster than 300 ms. Based on valid trials, we computed discriminability (d') as an index of how well participants could perceive the prime. The main effect of prime visibility was significant, F(1,

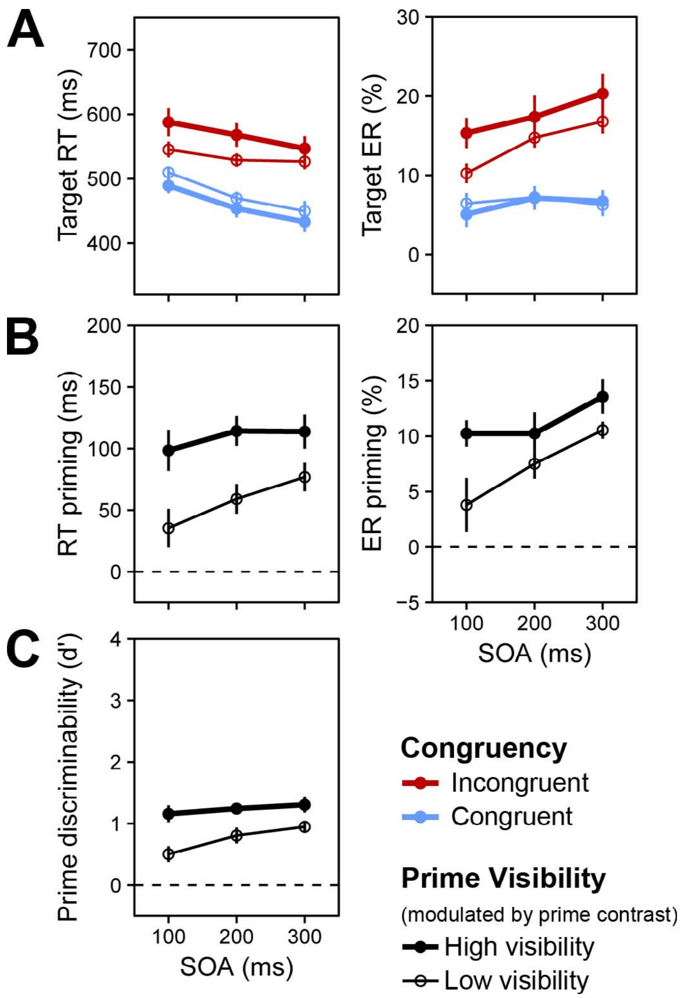

Figure 4. Group-level results of Experiment 1 where prime visibility was modulated by prime contrast. Red lines depict RT for incongruent trials, blue lines for congruent trials. Thick lines and thin lines depict data from conditions of high or low prime visibility, respectively. (A) Left panel: Mean correct RT in the choice RT task as a function of congruency, prime visibility, and SOA. Right panel: choice ER in the target discrimination task. (B) Net priming effects (incongruent minus congruent trials) in RT (left panel) and ER data (right panel). (C) Mean prime discriminability (d') in the prime discrimination task as a function of prime visibility and SOA. Error bars represent ±1 *SE* after correcting for between-participants variance.

15) = 6.4, $p = 0.023$, $\eta_p^2 = 0.30$, with higher d' scores on high ($M_{d'} = 1.24$) as compared with low ($M_{d'} = 0.75$) prime visibility. The main effect of SOA was also significant, $F(2, 30) = 4.5$, $p_{GG} = 0.032$, $\eta_p^2 = 0.23$, $\varepsilon = 0.74$, with mean d' scores of 0.83, 1.03, and 1.13 for 100, 200, and 300 ms SOA, respectively. Pairwise comparisons showed that discriminability was on average lower with 100 compared with 200 ms SOA ($p = 0.029$) but did not differ significantly otherwise. The interaction of Prime Visibility × SOA was not significant ($p_{GG} = 0.147$).

Explorative analyses

During postexperimental interviews, a subgroup of participants reported that they were consistently unaware of the prime stimuli throughout the experiment. Hence, we wondered if the use of the maximal mask contrast in both visibility conditions might have resulted in overly strong suppression effects for some participants, preventing them from reliably discriminating the primes even in the high visibility condition. To explore this possibility, we checked how many participants failed to reach a $d' \geq 0.5$ in the high visibility condition (averaged across SOAs). Indeed, seven out of 16 participants failed to reach this criterion. To explore if priming effects differed between participants who were able to discriminate the prime and those who were not, we split the sample into two groups: "unaware" participants with $d' < 0.5$ in the high visibility condition, and "aware" participants, who exceeded this criterion. The unaware group did not show any RT priming effects ($M = 0$ ms, $SE = 3.1$, averaged across conditions), $t(6) = 0.1$, $p = 0.896$. Across conditions, average prime discriminability did not differ from zero in the unaware participants ($M_{d'} = 0.12$, $SE = 0.07$), $t(6) = 1.8$, $p = 0.126$. Within aware participants, we observed a different pattern of results. Across all conditions, the aware group showed significant positive priming effects ($M = 147$ ms, $SE = 23.4$), $t(8) = 6.3$, $p < 0.001$. On average, prime discrimination performance was above chance level in the aware group ($M_{d'} = 1.7$, $SE = 0.23$), $t(8) = 7.1$, $p < 0.001$ (see the detailed analysis of individual differences below).

Discussion

In Experiment 1, we modulated prime visibility by adjusting prime contrast and kept mask contrast at a maximal level in both visibility conditions. On the group level, prime discrimination performance was reliably modulated by prime contrast: High contrast primes were discriminated better than low-contrast primes. We also observed reliable and robust priming effects. RTs were shorter, and ERs were lower when primes and targets were congruent rather than incongruent. Most important, priming effects were larger with high-contrast primes than with low-contrast primes. This finding suggests that CFS affects both prime discrimination performance and priming effects in the choice RT task in a comparable way.

The SOA effects in Experiment 1 differed from SOA effects under backward masking conditions that were previously reported in the literature. In our Experiment 1, SOA affected RT and ER, but we did not observe a significant interaction between SOA and congruency (cf. Mattler, 2003; Schmidt, 2002; Vorberg et al., 2003;

Vorberg et al., 2004). The absence of a significant modulation of priming effects by SOA might have resulted from a lack of statistical power because a relatively large group of participants was unable to discriminate the primes in either of the conditions and also did not show any traces of priming effects. Moreover, we varied the SOA between 100 and 300 ms, whereas backward masking studies generally use SOAs below 150 ms. Therefore, additional processes might have contributed to the priming effects at hand that were absent in previous studies. Notably, our Experiment 1 did not yield any evidence for clearly dissociable SOA effects on priming and prime discrimination, which could serve as a reliable indicator for dissociable processes of conscious perception and action priming (Schmidt & Vorberg, 2006; Vorberg et al., 2003). This is true for all levels of SOA including the 100-ms condition, a condition which has provided evidence for a dissociation between priming and prime visibility in studies that used backward masking procedures (e.g., Klapötke, Krüger & Mattler, 2011; Mattler, 2003; Vorberg et al., 2003; see also Schmidt & Schmidt, 2010 for priming effects of unconscious stimuli without masking).

To sum up, findings of Experiment 1 suggest that in CFS, the same factors determine priming effects and prime discrimination performance, namely prime contrast and SOA. At first glance, this finding seems to accord with the view that some residual awareness of the prime is necessary for eliciting priming during CFS (cf. Gelbard-Sagiv, Faivre, Mudrik, & Koch, 2016; Peremen & Lamy, 2014). However, priming effects and prime discrimination performance continued to depend on prime contrast and SOA even when prime discrimination performance was at moderately high levels. Together these findings point to a rather fundamental link between priming effects and conscious perception of the prime stimuli during CFS.

Experiment 2: Prime visibility modulated by prime contrast and mask contrast

Experiment 2 aimed to replicate and extend the results of Experiment 1 while ensuring that all participants could discriminate primes in the high visibility condition beyond chance level. To this end, we paired a medium-contrast mask with a full-contrast prime in the high visibility condition assuming that this should reduce perceptual suppression effects compared with the full-contrast mask used in Experiment 1. In the low visibility condition, we paired a low-contrast prime with an individually adjusted mask contrast that was matched to the participant's threshold. With this modified setup, we aimed to get a better understanding of the suppression mechanisms involved in CFS, which, as in BR (Levelt, 1965), are probably related to the relative difference in stimulus strength (here, modulated by contrast) between the primes and the masks. If priming effects and conscious perception are fundamentally related during CFS, we expected a similar pattern of results like in Experiment 1. Due to the better separation of high and low visibility conditions, we also expected more accentuated effects of prime visibility on priming and perception.

Method

Participants

Sixteen (10 female) participants with a mean age of 24.2 years ($SD = 3.12$ years) were tested from the same population and under the same conditions as in Experiment 1. None of them participated in the previous experiment.

Stimuli and procedures

Stimuli and procedures were the same as in Experiment 1 with the following exceptions (cf. Figure 2). In the high visibility condition, prime contrast was the same as in Experiment 1, but a medium mask contrast of 0.33 was used (constant across participants). In the low visibility condition, mask contrast was adjusted individually for each participant using the threshold contrast staircase test. The staircase started with a prime contrast of 0.06. For participants who showed ceiling performance in the threshold contrast test, we further reduced the prime contrast to 0.02 and repeated the staircase using this setting. In all other respects, the procedure and analysis was identical to Experiment 1.

Results

Figure 5 gives a summary of the group-level findings in Experiment 2: (A) shows performance in the choice RT task in terms of mean correct target RT and ER; (B) depicts the net priming effects (RT and ER on incongruent minus RT and ER on congruent trials, respectively); and (C) illustrates prime discriminability in the different experimental conditions.

Target RT

We excluded 649 trials (5.3% of all trials) in which participants gave a wrong response to the target. From the remaining trials, we excluded another 313 trials

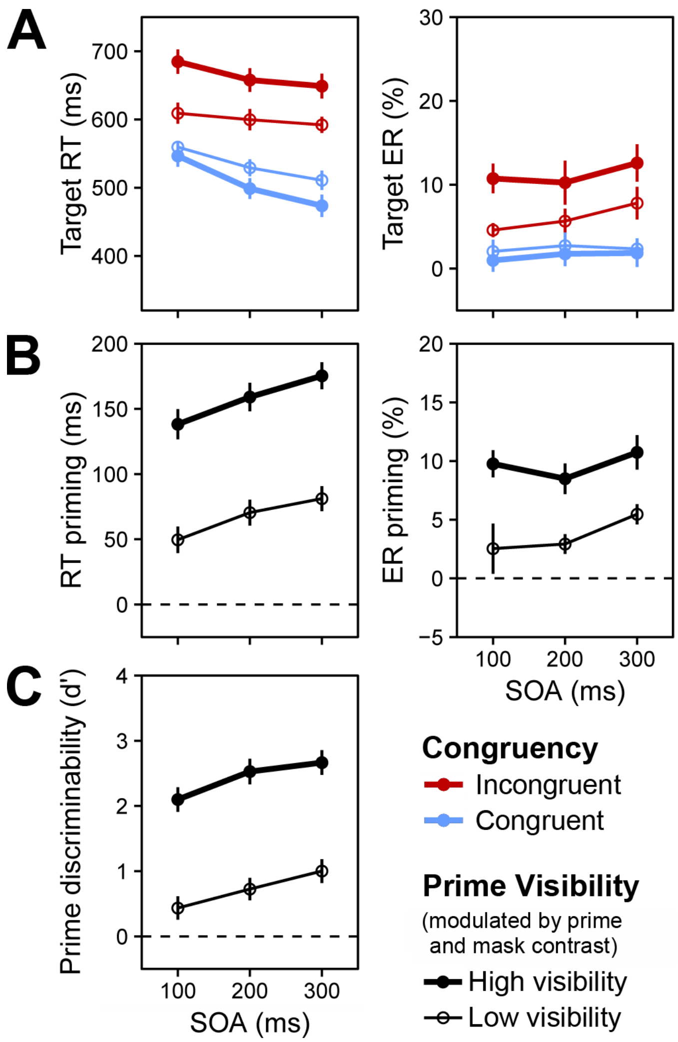

Figure 5. Group-level results of Experiment 2 where prime visibility was modulated by prime and mask contrast. Red lines depict RT for incongruent trials, blue lines for congruent trials. Thick lines and thin lines depict data from conditions of high or low prime visibility, respectively. (A) Left panel: Mean correct RT in the choice RT task as a function of congruency, prime visibility, and SOA. Right panel: Choice ER in the target discrimination task. (B) Net priming effects (incongruent minus congruent trials) in RT (left panel) and ER data (right panel). (C) Mean prime discriminability (d') in the prime discrimination task as a function of prime visibility and SOA. Error bars represent ±1 *SE* after correcting for between-participants variance.

(2.5% of all trials) that fell outside of ± 2.5 *SD* around the participants' mean correct RT for that condition. The main effect of congruency was significant, $F(1, 15) = 20.9$, $p < 0.001$, $\eta_p^2 = 0.58$, with 520 ms on congruent and 632 ms on incongruent trials. The main effect of SOA was significant, $F(2, 30) = 18.0$, $p_{GG} < 0.001$, $\eta_p^2 = 0.55$, $\varepsilon = 0.60$, with 600, 571, and 556 ms for 100, 200, and 300 ms SOA, respectively. The interaction of Congruency × Prime Visibility was significant, $F(1, 15) = 32.6$, $p < 0.001$, $\eta_p^2 = 0.68$, indicating larger RT priming effects with high prime visibility (158 ms vs. 67 ms). The interaction Congruency × SOA was also significant, $F(2, 30) = 7.6$, $p_{GG} = 0.005$, $\eta_p^2 = 0.34$, $\varepsilon = 0.76$, with priming effects of 94, 115, and 128 ms, for 100, 200, and 300 ms SOA, respectively. Pairwise comparisons showed that priming effects were significantly smaller with 100 ms compared with 300 ms SOA ($p = 0.016$) but did not differ otherwise ($ps \geq 0.124$). No other effects were significant ($ps \geq 0.083$).

Target ER

The main effect of congruency was significant, $F(1, 15) = 13.8$, $p = 0.002$, $\eta_p^2 = 0.48$, with 2.0% and 8.6% errors on congruent and incongruent trials, respectively. The main effect of prime visibility was significant, $F(1, 15) = 7.1$, $p = 0.018$, $\eta_p^2 = 0.32$, with 4.2% and 6.4% errors with low and high visibility, respectively. The interaction Congruency × Prime Visibility was significant, $F(1, 15) = 27.2$, $p < 0.001$, $\eta_p^2 = 0.64$, with larger ER priming effects when prime visibility was high (9.7% vs. 3.6%). No other effect was significant ($ps \geq 0.117$).

Prime discrimination performance

We excluded 20 trials (0.2%) of the prime discrimination trials because participants either did not respond or their response was faster than 300 ms. The main effect of prime visibility was significant, $F(1, 15) = 27.2$, $p < 0.001$, $\eta_p^2 = 0.64$ with mean d' scores of 0.72 and 2.43 for low and high prime visibility, respectively. The main effect of SOA was significant, $F(2, 30) = 24.6$, $p_{GG} < 0.001$, $\eta_p^2 = 0.62$, $\varepsilon = 0.70$, with mean d' scores of 1.27, 1.63, and 1.83 for 100, 200, and 300 ms SOA, respectively. Pairwise comparisons showed that discriminability was on average lower with 100 ms compared with 200 ms SOA ($p = 0.004$), lower with 100 ms compared with 300 ms SOA ($p < 0.001$), and also lower with 200 ms compared with 300 ms SOA ($p = 0.002$). The interaction of Prime Visibility × SOA was not significant ($p_{GG} = 0.719$).

Discussion

In Experiment 2 we created a low prime visibility condition using a low-contrast prime in combination with a mask contrast that was individually adjusted to the participants' discrimination thresholds. For the high prime visibility condition we used a high-contrast prime in combination with a medium-contrast mask. Compared with Experiment 1, these stimulus settings created a better separation between low and high visibility conditions regarding prime discriminability.

While the qualitative pattern of results was very similar to Experiment 1, the additional manipulation of mask contrast provided a more effective way to modulate CFS strength compared with the manipulation of prime contrast alone. As a result, Experiment 2 was more sensitive to the effects of our independent variables. Action priming effects on both RTs and ERs were modulated in the same way as prime discriminability. In contrast to Experiment 1, we found a significant interaction of Congruency × SOA on RTs, which we expected based on previous research (Mattler, 2003; Vorberg et al., 2003). This effect of SOA on priming effects was mirrored in a parallel effect of SOA on prime discriminability. These results provide further evidence for a close link between prime visibility and action priming effects in CFS.

Experiment 3: Prime visibility modulated by mask contrast

Experiment 3 tested if the relationship between prime visibility and action priming under CFS persisted if we modulated prime visibility exclusively via mask contrast. This was important because differences in prime contrast alone might explain part of the differences in priming effects, irrespective of prime visibility (e.g., Tapia & Breitmeyer, 2011; Waszak, Cardoso-Leite, & Gorea, 2007). Hence, we used the same low-contrast prime in both visibility conditions. For high prime visibility, we used a low-contrast mask. For low prime visibility, we increased the mask contrast individually up to participant's prime discrimination threshold in the same way as in Experiment 2. In Experiments 1 and 2 we had opted for a task-switching procedure because it allowed us to measure priming effects and prime discrimination while participants had the same cognitive set: They attended to primes as well as targets in each trial and selected the task according to the task cue that appeared simultaneously with the target. In this way, the two measures were highly comparable. However, the task-switching procedure departed from frequently reported priming studies that measured priming effects and prime discrimination in separate sections of the study (e.g., Mattler, 2003; Vorberg et al., 2003). In this traditional dissociation procedure, participants focus their attention completely on the target in the choice RT session and, conversely, attend fully to the prime in the prime discrimination session. Previous reports of dissociations between priming and prime discrimination were mostly based on the traditional dissociation procedure where participants adopted different task sets in separate blocks or sessions. In Experiment 3, we therefore adopted the traditional dissociation procedure to examine whether our previous findings depended on the task-switching procedure. If action priming effects were genuinely linked to perception in CFS, we expected to also replicate our findings of Experiments 1 and 2 using the traditional dissociation procedure.

Method

Participants

Sixteen (12 female) participants with a mean age of 23.5 years ($SD = 2.78$ years) were tested from the same population and under the same conditions as in Experiments 1 and 2. None of them participated in any of the previous experiments.

Stimuli and procedures

The same stimuli and procedures were used as in Experiments 1 and 2 with the following exceptions (cf. Figure 2). Prime visibility was modulated by mask contrast only. For the high visibility condition, a low-contrast prime was paired with a low-contrast mask (Michelson contrast 0.06). The low visibility condition had the identical prime contrast but an individually adjusted mask contrast, matched to participants' individual discrimination thresholds in the same way as in Experiment 2. A major difference to Experiments 1 and 2 was that priming and discriminability were assessed in separate sessions. Participants completed one initial training session in which they performed the target discrimination task for 384 trials (data from this training session was not included in the analyses). In the second session, participants repeated the threshold contrast test before they performed only the choice RT task (768 trials), and in the third session they performed only the prime discrimination task (768 trials). For the low visibility condition, we used the same individually adjusted mask contrast setting in both experimental sessions.

Results

Figure 6 gives a summary of the group-level findings in Experiment 3: (A) shows performance in the choice RT task in terms of mean correct target RT and ER; (B) depicts the net priming effects (RT and ER in incongruent minus RT and ER in congruent trials, respectively); and (C) illustrates prime discriminability in the different experimental conditions.

Target RT

We excluded 446 trials (3.6% of all trials) in which participants reported a wrong response to the target.

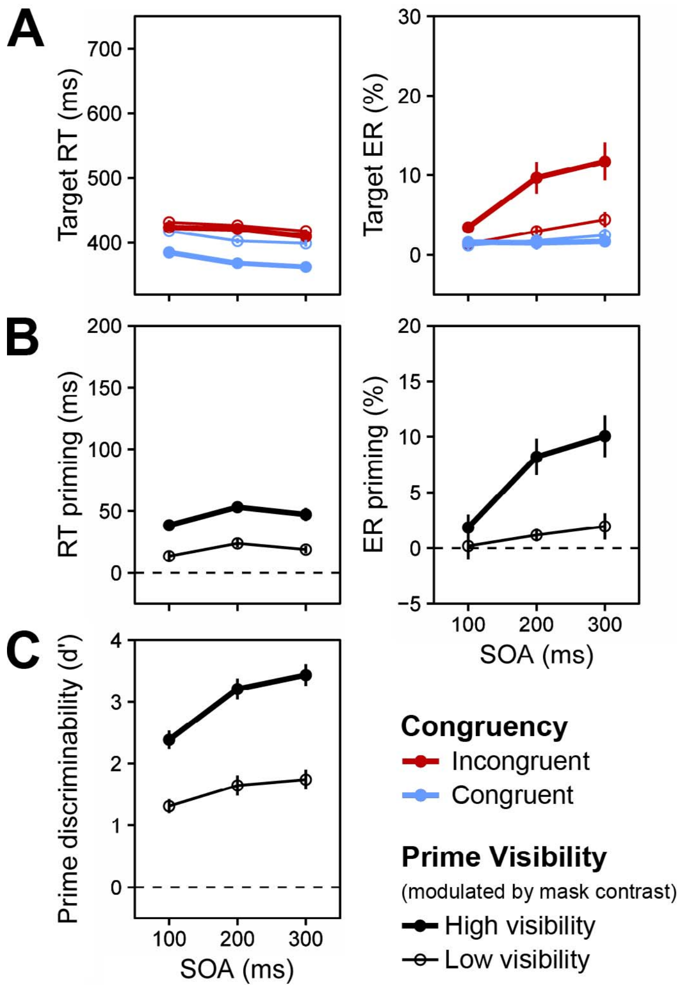

Figure 6. Group-level results of Experiment 3 where prime visibility was modulated by mask contrast and priming and prime discriminability were measured in separate sessions. Red lines depict RT for incongruent trials, blue lines for congruent trials. Thick lines and thin lines depict data from conditions of high or low prime visibility, respectively. (A) Left panel: Mean correct RT in the choice RT task as a function of congruency, prime visibility, and SOA. Right panel: Choice ER in the target discrimination task. (B) Net priming effects (incongruent minus congruent trials) in RT (left panel) and ER data (right panel). (C) Mean prime discriminability (d') in the prime discrimination task as a function of prime visibility and SOA. Error bars represent ±1 *SE* after correcting for between-participants variance.

From these trials, we excluded another 300 trials (2.4% of all trials) that fell outside of ±2.5 *SD* around the participants' mean correct RT for that condition. The main effect of congruency was significant, $F(1, 15) = 28.0$, $p < 0.001$, $\eta_p^2 = 0.65$, with 389 and 422 ms on congruent and incongruent trials, respectively. The main effect of prime visibility was significant, $F(1, 15) = 132.1$, $p < 0.001$, $\eta_p^2 = 0.90$, with 416 and 395 ms on trials with low and high prime visibility, respectively. The main effect of SOA was also significant, $F(2, 30) = 14.8$, $p_{GG} < 0.001$, $\eta_p^2 = 0.50$, $\varepsilon = 0.60$, with 414, 405, and 397 ms on trials with 100, 200, and 300 ms SOA, respectively. The interaction Congruency × Prime Visibility was significant, $F(1, 15) = 21.6$, $p < 0.001$, $\eta_p^2 = 0.59$, with 19 and 46 ms RT priming effects on trials with low versus high prime visibility. Finally, the interaction of Congruency × SOA was significant, $F(2, 30) = 4.6$, $p_{GG} = 0.036$, $\eta_p^2 = 0.23$, $\varepsilon = 0.66$, with 26, 38, and 33 ms RT priming effects on trials with 100, 200, and 300 ms SOA, respectively. Pairwise comparisons showed that priming effects were significantly smaller with 100 ms compared with 200 ms SOA ($p = 0.014$) but did not differ otherwise (ps ≥ 0.232). No other effects were significant (ps ≥ 0.648).

Target ER

The main effect of congruency was significant, $F(1, 15) = 14.5$, $p = 0.002$, $\eta_p^2 = 0.49$, with 1.7% and 5.6% errors on congruent and incongruent trials, respectively. The main effect of prime visibility was significant, $F(1, 15) = 26.2$, $p < 0.001$, $\eta_p^2 = 0.64$, with 2.3% and 4.9% errors on trials with low and high prime visibility, respectively. The main effect of SOA was significant, $F(2, 30) = 14.6$, $p_{GG} < 0.001$, $\eta_p^2 = 0.49$, $\varepsilon = 0.95$, with 1.9%, 4.0%, and 5.1% errors on trials with 100, 200, and 300 ms SOA, respectively. Pairwise comparisons showed that ER was lower with 100 ms compared with 200 ms ($p = 0.003$) and 300 ms SOA ($p < 0.001$) but did not differ between SOAs of 200 and 300 ms ($p = 0.638$). The interaction of Congruency × Prime Visibility was significant, $F(1, 15) = 20.1$, $p < 0.001$, $\eta_p^2 = 0.57$, with 1.1% versus 6.7% ER priming effects on trials with low versus high prime visibility. No other effect was significant (ps ≥ 0.055).

Prime discrimination performance

From all prime discrimination trials, we excluded 612 trials (5.0%) because participants either did not respond or their response was faster than 300 ms. The main effect of prime visibility was significant, $F(1, 15) = 35.0$, $p < 0.001$, $\eta_p^2 = 0.70$, with mean d' scores of 1.57 and 3.01 on trials with low and high prime visibility, respectively. The main effect of SOA was significant, $F(2, 30) = 22.8$, $p_{GG} < 0.001$, $\eta_p^2 = 0.60$, $\varepsilon = 0.75$, with mean d' scores of 1.85, 2.43, and 2.59 on trials with 100, 200, and 300 ms SOA, respectively. Pairwise comparisons showed that mean d' was significantly smaller with 100 ms compared with 200 ms ($p = 0.001$) and 300 ms SOA ($p < 0.001$) but did not differ between SOAs of 200 and 300 ms ($p = 0.148$). The interaction of Prime Visibility × SOA was also significant, $F(2, 30) = 3.7$, $p_{GG} = 0.049$, $\eta_p^2 = 0.20$, $\varepsilon = 0.77$.

Explorative comparison between Experiment 2 and Experiment 3

A major difference between Experiments 2 and 3 concerns the procedure for measuring prime discrimination performance. On the other hand, the low visibility condition was set up in the same way in the two experiments (cf. Figure 2). Therefore, we considered it worthwhile to compare the data of the low visibility condition in the two experiments in order to explore whether priming effects and prime discrimination performance change when measured in the same sessions with a dual task (Experiment 2) or measured in two separate sessions and tasks (Experiment 3). To that end, we treated net priming effects and d' scores as dependent variables in 2 (Experiment 2 vs. Experiment 3, between-participants) × 3 (SOA, within-participants) mixed ANOVAs and focused on the main effects and interactions of the experiment variable.

RT priming effects differed as a function of experiment, $F(1, 30) = 4.3$, $p = 0.046$, $\eta_p^2 = 0.13$. RT priming effects were smaller in Experiment 3 ($M = 18.8$ ms, $SE = 5.67$) compared with Experiment 2 ($M = 67.1$ ms, $SE = 22.57$). The interaction of Experiment × SOA was not significant, $F(2, 60) = 2.9$, $p_{GG} = 0.076$, $\eta_p^2 = 0.09$, $\varepsilon = 0.80$. ER priming effects did not differ significantly with experiment, $F(1, 30) = 0.4$, $p = 0.529$, $\eta_p^2 = 0.01$, and there was no interaction of Experiment × SOA with regard to ER priming, $F(2, 30) = 0.5$, $p_{GG} = 0.609$, $\eta_p^2 = 0.02$. Finally, prime discrimination performance differed as a function of Experiment, $F(1, 30) = 4.6$, $p = 0.039$, $\eta_p^2 = 0.13$, with higher average d' scores in Experiment 3 ($M_{d'} = 1.6$, $SE = 0.34$) compared with Experiment 2 ($M_{d'} = 0.72$, $SE = 0.19$). The interaction of Experiment × SOA was not significant, $F(2, 60) = 0.5$, $p_{GG} = 0.549$, $\eta_p^2 = 0.02$, $\varepsilon = 0.82$.

Discussion

In Experiment 3, we used the same low-contrast prime in both visibility conditions and modulated visibility exclusively via the mask contrast. For the low visibility condition, we individually adjusted mask contrast to the participants' discrimination threshold whereas, for the high visibility condition, we used a low-contrast mask. Also, we measured priming effects and prime discrimination performance in separate experimental sessions. Despite these differences, the results of Experiment 3 further corroborate a strong link between prime discrimination performance and action priming effects in CFS, as both measures were modulated in parallel by mask contrast and SOA.

The results of Experiment 3 yield some differences to our previous findings. RTs were generally shorter in the choice RT task, and the priming effects were smaller in size despite the better prime discrimination performance compared with Experiment 2. Most likely, these discrepancies stem from the simpler general task set in Experiment 3 where participants could focus on one task throughout a complete experimental session, without the requirement to switch between tasks according to the task cue. Thus, in the choice RT task, participants could fully attend to the target stimulus whereas in the prime discrimination task they could fully attend to the prime. Also, because we measured prime discrimination in a separate follow-up session after the participants had already extensive experience with the stimuli, the measured prime discriminability might have been less representative of prime visibility during the choice RT task. In the follow-up session, when presented with the prime discrimination task, prime discriminability could have shifted towards higher values due to perceptual learning effects (cf. Ludwig, Sterzer, Kathmann, Franz, & Hesselman, 2013). Despite these differences between experiments, the relative effects of our experimental variables on priming and prime discrimination were parallel in all experiments. These findings provide strong evidence that the link between visual perception and action priming in CFS did not result from the task-switching procedure nor the differences in prime contrast in Experiments 1 and 2. Instead, perception and priming seem to be fundamentally linked in CFS.

Individual differences in perception and priming

The findings discussed so far suggest that in CFS, priming effects were reduced when visibility of the prime was low, compared with high prime visibility. While our experimental manipulations established two distinct levels of prime visibility on the group level, they did not warrant equal discriminability between participants. A tentative examination of individual participant data revealed considerable interindividual variability in perceptual performance. This observation parallels previous reports of substantial variability in perceptual CFS effects between different participants of the same experiment (e.g., Gayet & Stein, 2017; Yamashiro et al., 2014). Interestingly, we also found considerable differences in RT and ER priming effects between individual participants. Therefore, in an additional explorative analysis, we fathomed if individual differences in perception might be related to the size of individual priming effects. Based on the group level findings, we hypothesized that participants with lower prime discriminability levels should also show smaller priming effects. Conversely, participants with higher prime discriminability levels should produce more substantial priming effects. Hence, we looked at the relationship between individual d' scores and RT/ER priming effects in all experimental conditions.

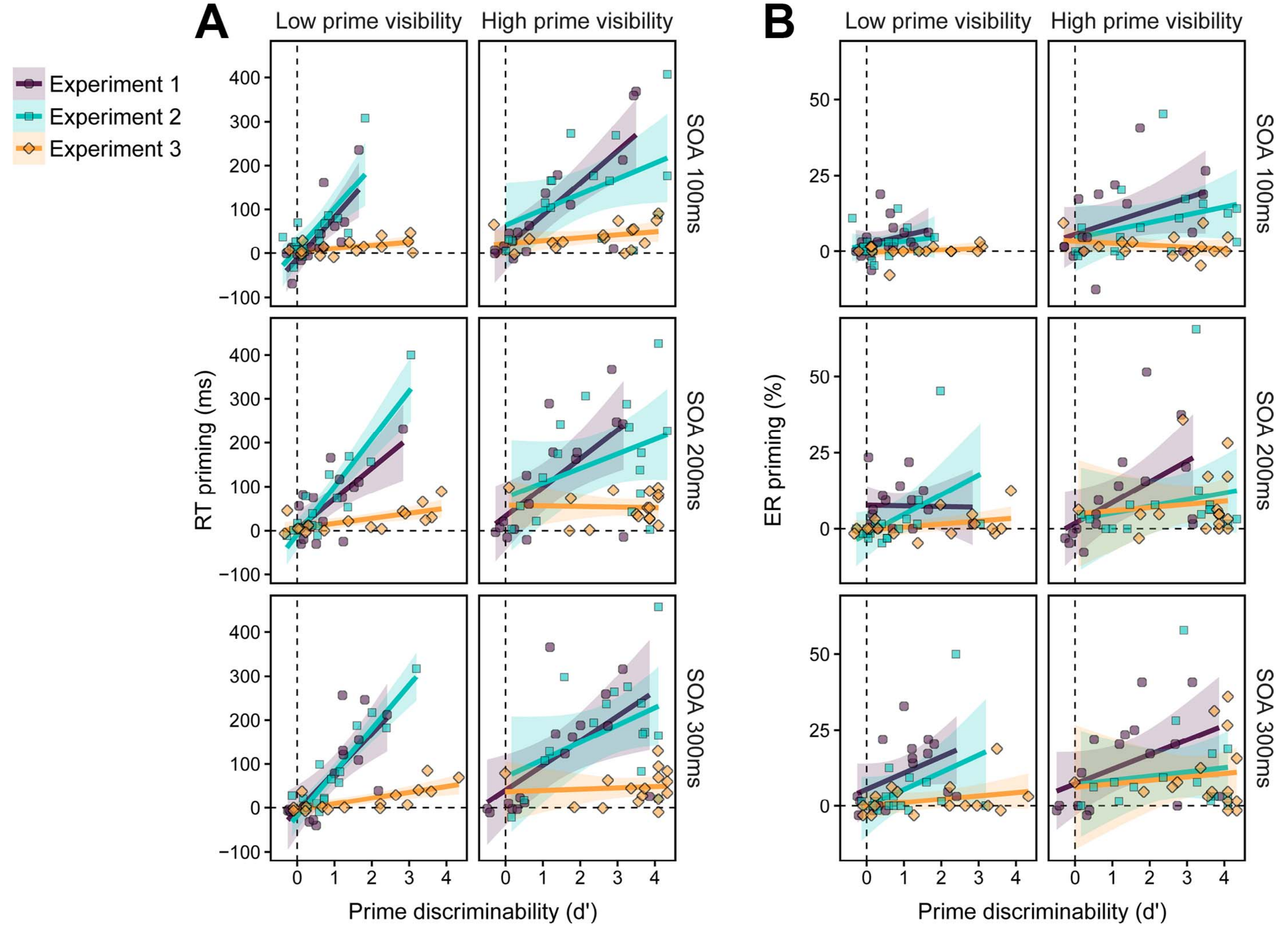

Figure 7. Explorative analyses of individual differences in perception and action priming—comparison between Experiments 1, 2, and 3. Data points represent individual participants. Regression lines depict a linear fit with standard errors of the estimates as shaded areas, split for experiments. (A) The relationship between individual *d′* scores as a measure of prime visibility and RT priming effects. RT priming effects were computed as the difference between mean correct RT in incongruent minus mean correct RT in congruent trials. (B) The relationship between individual *d′* scores and ER priming effects. ER priming effects were computed as the difference between ER in incongruent minus ER in congruent trials. Across conditions, the analysis indicated a positive relationship between individual *d′* scores and RT and ER priming effects (Table 1) as well as ER priming effects (Table 2).

Positive correlations between perception and priming in all experiments

Figure 7 illustrates the variability of individual *d'* scores and priming effects. To explore our hypothesis that participants with lower *d′* scores also show smaller priming effects compared with participants with higher *d′* scores, we first calculated the Pearson correlation coefficients between individual *d′* scores and RT priming effects, separately for each experiment and condition (see Table 1 and Figure 7A). Pearson coefficients were transformed to Fisher's *z* to test if correlations were consistently positive across experimental conditions. As a supplementary analysis, we fitted a linear model treating individual *d′* as a predictor for RT priming effects (see Figure 7A for the linear fits). The slope of the linear fit represents the change in priming per unit *d′*. Hence, a positive slope indicates the extent to which priming increases with a gain in prime discriminability. The positive relationships between *d′* and RT priming effects were evaluated by testing if the correlations and slopes were consistently positive across the six conditions (one-tailed *t* tests against zero; see final three columns of Table 1).

As summarized in Table 1, the correlations between individual *d′* scores and RT priming effects were positive in 17 out of 18 tests. For single conditions, the correlations were strong and significant in all low prime visibility conditions in all three experiments. Across conditions, the positive relationship remained signifi-

Dataset	Low prime visibility 100 ms	Low prime visibility 200 ms	Low prime visibility 300 ms	High prime visibility 100 ms	High prime visibility 200 ms	High prime visibility 300 ms	Positive relationship *M*	Positive relationship *t*(5)	Positive relationship *p*
Experiment 1									
r(14)	0.74***	0.71**	0.74**	0.81***	0.65**	0.59*			
z	0.96	0.88	0.95	1.13	0.77	0.68	0.89	13.9	<0.001
Intercept	−12.5	3.2	−6.0	13.9	33.1	40.6			
Slope	95.0	69.3	87.5	73.1	65.3	56.1	74.4	12.6	<0.001
Experiment 2									
r(14)	0.75***	0.90***	0.93***	0.47†	0.39	0.44†			
z	0.97	1.48	1.63	0.51	0.41	0.47	0.91	4.1	0.005
Intercept	8.6	−8.3	−18.2	64.1	75.7	70.6			
Slope	94.1	108.5	99.1	35.3	33.0	39.3	68.2	4.7	0.003
Experiment 3									
r(14)	0.50*	0.66**	0.72**	0.33	−0.05	0.09			
z	0.55	0.79	0.90	0.35	−0.05	0.09	0.44	2.8	0.018
Intercept	4.0	5.0	−4.3	22.4	57.7	37.1			
Slope	7.2	11.5	13.3	6.7	−1.4	3.0	6.7	3.0	0.015

Table 1. Relationship between individual d' scores and RT priming effects in Experiments 1, 2, and 3. *Notes*: †$p < 0.10$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

cant in all experiments. The results of the linear regression analyses paralleled these observations and revealed positive slopes in 17 out of 18 tests. Across conditions, the slopes were significantly positive in all experiments. In the next step, we conducted analogous analyses for ER priming effects (see Figure 7B and Table 2, respectively).

As shown in Table 2, 16 out of 18 tests revealed positive correlations and slopes between individual d' and ER priming effects. Although the correlations were smaller for ER priming compared with RT priming analyses, the positive relationships were significant when averaged across the six conditions in both Experiments 1 and 2. In Experiment 3, the relationship was weaker and nonsignificant when averaged across conditions. The linear regression analyses showed the same qualitative pattern of results for ER priming as was observed for RT priming, with significantly positive slopes, across conditions, in all three experiments (see Figure 7B for the linear fits). Taken together, the relationship between individual d' scores and RT/ER priming effects further corroborates the link between perception and priming in CFS. Moreover, these analyses showed that the relationship between the two measures was robust for the low prime visibility conditions, suggesting that in CFS, individual differences in perceptual suppression correlate with prim-

Dataset	Low prime visibility 100 ms	Low prime visibility 200 ms	Low prime visibility 300 ms	High prime visibility 100 ms	High prime visibility 200 ms	High prime visibility 300 ms	Positive relationship *M*	Positive relationship *t*(5)	Positive relationship *p*
Experiment 1									
r(14)	0.28	−0.02	0.42	0.41	0.53*	0.43†			
z	0.28	−0.02	0.44	0.43	0.58	0.46	0.36	4.2	0.004
Intercept	2.4	7.7	5.5	5.7	1.8	7.3			
Slope	2.9	−0.2	5.3	4.0	6.8	4.8	3.9	4.0	0.005
Experiment 2									
r(14)	0.19	0.48†	0.40	0.32	0.20	0.13			
z	0.19	0.52	0.42	0.33	0.21	0.13	0.3	4.8	0.002
Intercept	1.9	−1.8	−0.2	4.6	2.9	7.1			
Slope	1.5	6.5	5.6	2.5	2.2	1.4	3.3	3.7	0.007
Experiment 3									
r(14)	0.22	0.37	0.31	−0.25	0.11	0.11			
z	0.22	0.38	0.32	−0.25	0.11	0.11	0.15	1.6	0.081
Intercept	−0.4	−0.5	0.0	3.4	4.8	6.2			
Slope	0.4	1.0	1.1	−0.7	1.1	1.1	0.7	2.4	0.033

Table 2. Relationship between individual d' scores and ER priming effects in Experiments 1, 2, and 3. *Notes*: †$p < 0.10$; *$p < 0.05$.

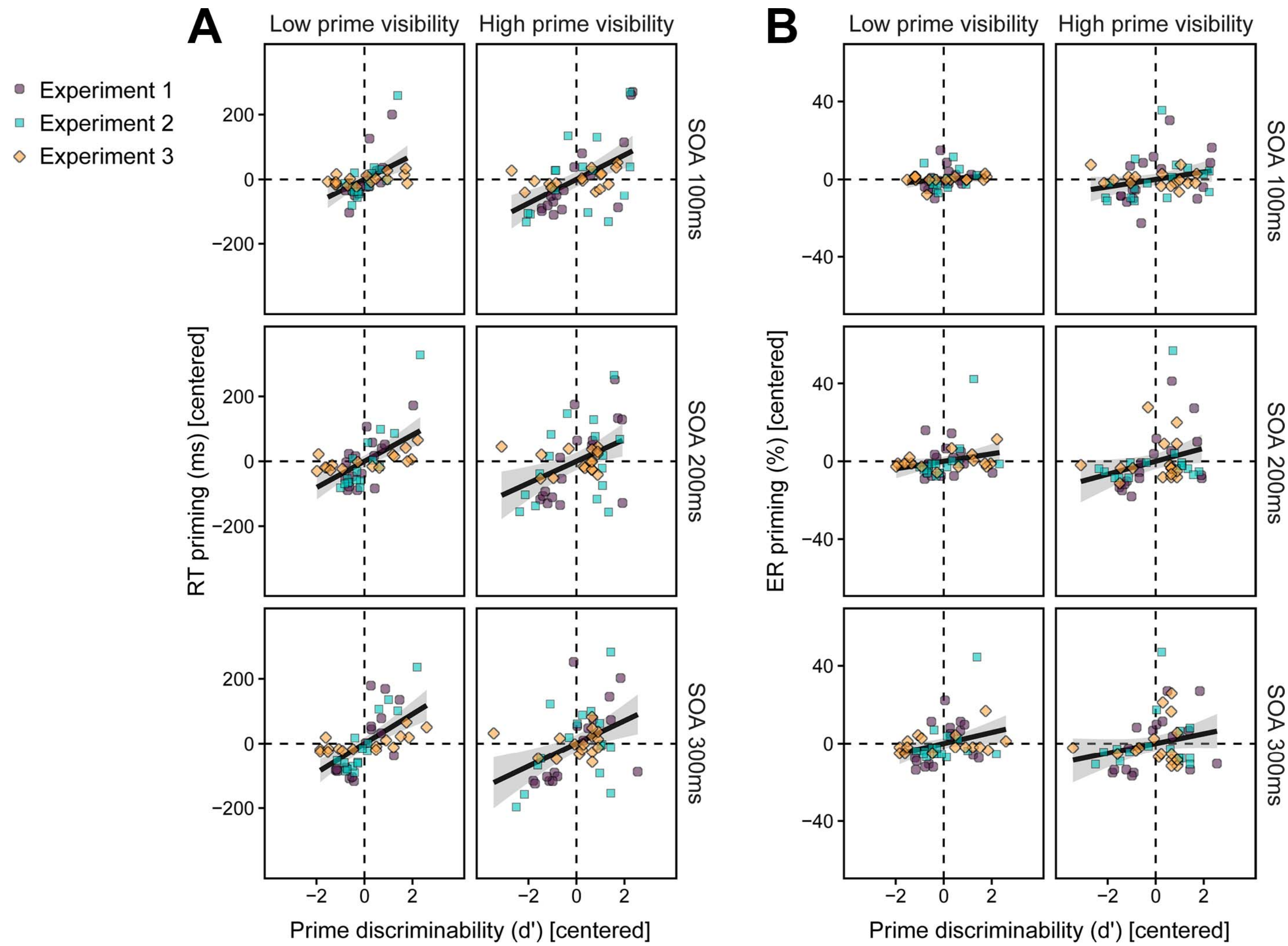

Figure 8. Explorative analyses of individual differences in perception and action priming across all three experiments. Data points represent individual participants. For each experiment, the data were centered on the mean to compensate for the absolute differences between experiments and to focus the analysis on the relative differences between subjects. Regression lines depict a linear fit with standard errors of the estimates as shaded areas, across all three experiments. (A) The relationship between individual d' scores as a measure of prime visibility and RT priming effects. (B) The relationship between individual d' scores and ER priming effects. Across experiments and conditions, the data confirmed a positive relationship between individual d' scores and RT priming effects as well as ER priming effects (see Table 3).

ing effects when prime discriminability is close to the individual discrimination threshold.

To improve statistical power and verify the robustness of the positive relationship, we also pooled the data from the three experiments and recalculated the correlation and regression coefficients based on 48 data points per condition resulting from the 16 participants in each of the experiments. Because the distribution of d' scores and priming effects differed between experiments, we centered each dataset on the respective sample mean. The centering of the data preserved the relative differences in d' scores and priming effects within experiments and controlled for distortions by absolute differences between experiments. Figure 8 presents the centered datasets, together with the respective linear fits across experiments. Table 3 summarizes the correlations and slopes for centered d' scores and centered RT/ER priming effects.

The analyses of centered data summarize and confirm our results from individual experiments. Across datasets, we observed moderate to strong positive correlations between individual d' scores and RT priming, as well as positive slopes of the corresponding linear fits, in all conditions. We also obtained positive correlations between individual d' scores and ER priming effects, and positive slopes of the corresponding linear fits, in all conditions. For both RT and ER priming effects, the positive relationship

	Low prime visibility			High prime visibility			Positive relationship		
Effect	100 ms	200 ms	300 ms	100 ms	200 ms	300 ms	*M*	*t*(5)	*p*
RT priming									
r(46)	0.49***	0.59***	0.63***	0.55***	0.42**	0.44**			
z	0.54	0.68	0.74	0.62	0.45	0.47	0.58	12.3	<0.001
Intercept	0.0	0.0	0.0	0.0	0.0	0.0			
Slope	37.0	40.5	45.6	37.6	33.7	35.3	38.3	22.0	<0.001
ER priming									
r(46)	0.18	0.25†	0.32*	0.26†	0.30*	0.23			
z	0.18	0.26	0.33	0.27	0.31	0.24	0.26	12.5	<0.001
Intercept	0.0	0.0	0.0	0.0	0.0	0.0			
Slope	1.0	1.9	2.9	1.9	3.3	2.5	2.3	6.8	<0.001

Table 3. Relationship between prime visibility and priming effects across all experiments in this study. *Notes*: †$p < 0.10$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

was significant across experimental conditions (see final three columns in Table 3). The results of these explorative analyses, therefore, suggest that the extent to which individual participants showed RT and ER priming effects depended on how well they could discriminate the primes. This finding points to another difference between CFS and backward masking where priming effects of individual participants dissociate from individual differences in prime discrimination performance (Albrecht et al., 2010).

General discussion

Our study examined whether processing for perception and processing for action priming are independent during CFS as it has been reported from backward masking studies. We employed a well-established priming paradigm with arrow stimuli and examined priming effects and prime discrimination performance in parallel tasks with the same number of trials per condition in each task. Within participants, we manipulated prime visibility and varied the prime–target SOA in a range, which overlapped with the SOA that is typically used in backward masking studies. In three experiments we found stronger priming effects in conditions where prime visibility was higher. Moreover, the SOA had parallel effects on priming and perception. Finally, an analysis of individual differences revealed that participants' prime discrimination performance was predictive of their priming effects. Our results paint a clear and coherent picture, which suggests that in CFS, prime perception and priming effects are tightly linked: When the contrast of primes is reduced, or the contrast of masks is increased both prime perception and priming effects are suppressed to a similar degree.

CFS differs from other perceptual blinding techniques such as backward masking due to its robust and sustained effects on conscious perception (Breitmeyer, 2015; Faivre, Berthet, & Kouider, 2012; Izatt, Dubois, Faivre, & Koch, 2014; Kim & Blake, 2005; Lamme, 2015; Peremen & Lamy, 2014). In consequence, there have been high hopes regarding the potential of CFS for research on consciousness and the processing of unconscious stimuli. Several CFS studies reported promising findings of high-level semantic processing of unconscious visual stimuli under CFS conditions (e.g., Bahrami et al., 2010; Mudrik, Breska, Lamy, & Deouell, 2011; Sklar et al., 2012). However, some of these findings could not be replicated by other research groups (Hesselmann & Knops, 2014; Moors, Boelens, van Overwalle, & Wagemans, 2016; Moors & Hesselmann, 2018) and several authors suggested to adopt a more rigorous methodology when using CFS to study conscious and unconscious visual processing (e.g., Hesselmann, Darcy, Rothkirch, & Sterzer, 2018; Kerr, Hesselmann, Räling, Wartenburger, & Sterzer, 2017; Moors et al., 2017; Moors et al., 2019; Yang & Blake, 2012). CFS does not evade the most frequently discussed problem of consciousness research, namely a lack of methodological strictness in measures of masking effects. This problem includes a number of specific fallacies that have been discussed extensively in the literature (e.g., Eriksen, 1960; Holender, 1986; Merikle, 1992; Merikle & Daneman, 1998; Reingold & Merikle, 1988; Schmidt, 2015; Schmidt & Vorberg, 2006; Shanks, 2017). To omit such shortcomings in our study, we employed a classical signal detection approach and gave our participants the straightforward task of reporting which of the two possible prime identities they saw (Green & Swets, 1966; Macmillan & Creelman, 2005).

Note that the present approach did not strive to establish conditions of total prime invisibility, as we instead varied prime visibility experimentally. Nevertheless, a subset of our data might be used to appraise conditions with zero prime visibility. The prime discrimination performance of seven participants in Experiment 1 resembles cases of zero prime visibility, and these participants did not show any traces of priming effects. This observation fits the fact that across participants, prime discriminability correlated positively with priming, which suggests that the extent of priming, under CFS, depends on the degree of visibility. The finding that the same experimental variables, in all experiments, had parallel effects on priming and visibility deviates from the pattern of dissociations typically obtained under backward masking conditions (cf. Figure 1). Therefore, our results suggest that priming is not independent of perception in CFS, and predict the absence of priming in conditions of "zero visibility."

Whether zero visibility conditions are necessary or desirable to argue for the independence of priming and perception has been critically discussed in the literature (e.g., Reingold & Merikle, 1988; Schmidt & Vorberg, 2006). In this context, it is important to note that evidence for unconscious processing under zero visibility is inconclusive unless the visibility test has sufficient sensitivity and measures conscious processing exhaustively (e.g., Schmidt & Vorberg, 2006). In the CFS literature, convincing demonstrations of priming despite zero visibility are the exception rather than the rule. Moreover, certain methodological decisions can promote nonzero priming effects at zero visibility. For example, if visibility is measured with a small number of trials in a separate control experiment, the visibility test is noisy and insensitive. Alternatively, if the analysis is selectively constrained to participants who objectively or subjectively did not see the prime (depending on some set criterion), and participants with higher visibility values are excluded post hoc, spurious dissociations between priming and visibility are likely to occur (cf. Shanks, 2017). Dissociations that result from such procedures, therefore, do not provide serious evidence for unconscious processing with zero visibility. Because of the potential problems associated with the zero visibility approach, we preferred an approach in which we establish different degrees of visibility using suitable experimental manipulations and investigate the effects of these manipulations on priming (e.g., Becker & Mattler, 2019; Wernicke & Mattler, 2019). This approach is common in the backward masking literature (e.g., Mattler, 2003; Mattler & Palmer, 2012; Vorberg et al., 2003), and we thought it is worthwhile to apply it to the study of priming in CFS. We believe that this approach has the potential to resolve some of the ongoing debate on the extent of unconscious processing in CFS and encourage its use in future CFS studies on priming.

As typical of CFS experiments, we manipulated prime visibility by reducing the contrast of the primes and by increasing the contrast of the masks (cf. Hesselmann et al., 2011; Izatt et al., 2014; Ludwig, Sterzer, Kathmann, & Hesselmann, 2016; Yang et al., 2010). We assumed that our experimental manipulations influenced the mechanisms that reduce perception of the prime because stimulus contrast is a critical determinant of the strength of interocular suppression (Brascamp et al., 2015; Fox & Check, 1966; Lee, Blake, & Heeger, 2005; Levelt, 1965). Although Levelt's (1965) classical propositions about the relationship of stimulus strength and perceptual dynamics during BR refer to the variables of dominance duration and alternation rate (which we did not assess in our experiments), our results are compatible with these "laws" of BR. According to Levelt's first proposition, increasing the stimulus strength for one eye increases the perceptual predominance of that eye's stimulus. In Experiments 1 and 2, we increased the prime contrast, which increased its perceptibility (indexed by higher prime discriminability). Conversely, in Experiments 2 and 3 we increased the mask contrast, which increased the masks' perceptual predominance (indexed by lower prime discriminability). Levelt's updated second and third propositions (Brascamp et al., 2015) predict that an increased difference in stimulus strength leads to higher dominance durations of the stronger stimulus and fewer alternations. With our low visibility conditions, we increased the difference in stimulus strength by reducing prime contrast (Experiments 1 and 2) and increasing mask contrast (Experiments 2 and 3), which resulted in higher dominance of the masks (indexed by lower prime discriminability). Thus, our findings with CFS correspond to Levelt's propositions for BR, which supports the view that CFS and BR indeed tap into the same, presumably early stages of visual processing (cf. Han, Lunghi, & Alais, 2016, who reported similarities in spatiotemporal tuning between CFS and BR).

The view that CFS and BR relate to early stages of visual processing is supported by neuroimaging studies on the effects of stimulus contrast on interocular suppression (e.g., Hesselmann et al., 2011; Lee & Blake, 2002; Lee et al., 2005; Ludwig et al., 2016; Yamashiro et al., 2014; Yuval-Greenberg & Heeger, 2013). For example, Yuval-Greenberg and Heeger (2013) implemented three contrast levels of a grating stimulus in each participant. The grating was surrounded by a ring-shaped CFS mask that was presented either to the same or the other eye as the grating. The spatially nonoverlapping configuration of the stimuli allowed tracking the BOLD signal changes in retinotopic cortical locations corresponding to the grating. The signal magnitude which the grating elicited in early visual areas (V1–V3) depended on its contrast. More importantly, interocular suppression further reduced the signal markedly: If a low-contrast grating was interocularly suppressed, its signal was indistinguishable from a control condition, where no grating was presented at all. The dependence of the BOLD signal on contrast and interocular suppression was already present in area V1, but the signal reductions propagated to downstream areas V2 and V3 (Yuval-Greenberg & Heeger, 2013).

CFS differs from other masking procedures like backward masking regarding the time that the prime could be processed without disturbances. In CFS, primes are presented simultaneously with masks that could reduce the bottom-up signal of the prime from the very start. Only a few studies inform about the effects of bottom-up signal strength of primes in action priming paradigms (e.g., Tapia & Breitmeyer, 2011; Vath & Schmidt, 2007; Waszak et al., 2007). For example, Vath and Schmidt (2007) varied the saturation of colored primes and found stronger priming effects in the lateralized readiness potentials for primes with high compared with low saturation. Tapia and Breitmeyer (2011) varied the luminance contrast of primes and found a nonlinear increase of priming effects in a choice RT task: At low levels of contrast, priming effects increased by little increases of prime contrast; at higher contrast levels, however, priming effects were not much enhanced by further increases in prime contrast. These findings accord with the view that action priming requires a minimum level of initial bottom-up signal energy before SOA becomes the major driving force for priming effects (Neumann, 1990; Schmidt et al., 2011; Schmidt, Niehaus, & Nagel, 2006; VanRullen, 2007; Vorberg et al., 2003).

So far, we have advocated the view that priming effects during CFS are linked to prime visibility. Could the observed differences in priming between low and high visibility conditions be alternatively explained by differences in the primes' contrast? In Experiments 1 and 2, we manipulated the primes' visibility by adjusting their contrast level. Therefore, the differences in priming between the visibility conditions could indeed be (at least partly) explained by differences in prime contrast. However, this does not apply for Experiment 3, where prime contrast was held constant across the two visibility conditions. Moreover, the pattern of individual differences in the high visibility conditions of all experiments speaks against an explanation based on prime contrast alone. Although prime (and mask) contrast were held constant across participants, priming effects continued to correlate with visibility, which differed between participants. Hence, while the relative contrast of primes and masks determine prime visibility (in line with Levelt's propositions), a high prime contrast by itself does not warrant priming in the absence of visibility (which would be the case in backward masking). However, we suspect that the extent to which contrast modulates visibility (and consequently priming) might depend on the individual expression of sensory eye dominance. This could explain why the same contrast settings can result in zero visibility in some observers (with pronounced eye dominance) and higher visibility in other observers (with less pronounced eye dominance).

In this perspective, our finding that visibility and priming depend on the relative contrast of primes and masks supports the view that CFS affects early levels of prime processing. In consequence, the bottom-up stimulus energy of the prime is drastically reduced by CFS, such that it might not suffice to elicit a priming effect independent of perception. With backward masking, on the other hand, usually high-contrast primes precede the presentation of the mask, which produce priming effects that increase with increasing SOA independent of the perceptual effects of the mask (e.g., Vorberg et al., 2003). An early locus of CFS is also consistent with most theoretical accounts of BR, the precursor of CFS, which have attributed BR to mechanisms at early levels in the visual hierarchy (Breitmeyer, Koç, Öğmen, & Ziegler, 2008; Lin & He, 2009; Zadbood, Lee, & Blake, 2011; Zimba & Blake, 1983). In line with this view, neurophysiological studies demonstrated that CFS and BR affect stimulus processing at early stages in the visual processing hierarchy (Haynes, Deichmann, & Rees, 2005; Lee & Blake, 2002; Wunderlich, Schneider, & Kastner, 2005; Yuval-Greenberg & Heeger, 2013; Zadbood et al., 2011).

Therefore, CFS seems to differ from other masking procedures by the locus of the mechanism that reduces the conscious perception of the stimuli. Our findings provide strong evidence for the view that CFS affects action priming in the same way as prime discrimination performance because CFS interferes with the earliest levels of prime processing, thus impeding every type of processing that follows, whether it is processing for perception or processing for action. This view is also supported by a recent fMRI study by Ludwig et al. (2016). These authors studied differences between dorsal and ventral stream processing of object categories (faces vs. tools) during different levels of CFS strength, which they manipulated via five distinct levels of mask contrast. They found that distributed cortical activation patterns become increasingly category-unspecific when mask contrast increases. This reduction in representational fidelity was found in ventral as well as dorsal visual areas. The decrease in category-specific information more closely resembled the linear decrease in conscious perception in the ventral stream than in the dorsal stream, which accords with the view that the ventral stream is associated with conscious perception. During full suppression, the pattern of activations did not carry enough information to classify between stimulus categories in either of the cortical areas. These results are consistent with the view that CFS affects both processing for perception in the ventral pathway and processing for action in dorsal areas (see also Hesselmann et al., 2011; Hesselmann & Malach, 2011; Ludwig & Hesselmann, 2015). In light of our findings and the results of Ludwig et al. (2016), we speculate that stimulus processing for both perception and action is disturbed by CFS at a level below the division into dorsal and ventral streams.

Parallel effects of CFS on both perception and priming separate this masking technique from several other techniques that have revealed a dissociation between perception and priming. Such a distinction between masking techniques is consistent with the proposal of a functional hierarchy of unconscious processing levels that underlie conscious perception (Breitmeyer, 2015). This conception opens the opportunity to disturb conscious perception by interventions at different levels of unconscious processing and to locate different masking techniques within this hierarchy (see Wernicke & Mattler, 2019). Based on studies like that of Sklar et al. (2012), which argued for semantic priming during CFS, Breitmeyer (2015) located CFS at a level "nearly as high as the level of backward pattern masking or metacontrast" (p. 245). This location is called into question by our present findings, which suggest placing it at the very low end of the hierarchy proposed by Breitmeyer (2015).

Conclusion

Our results confirm that CFS is a powerful technique for reducing perceptual discriminability of a stimulus. The magnitude of this reduction is reliably modulated by the relative contrast of the mask and the masked stimulus. We consistently found that an increase in CFS masking strength reduces a stimulus' potential to facilitate motor responses to subsequent targets. Our results suggest that perception and priming are closely linked during CFS and that priming is unlikely if perceptual suppression is complete. The present findings therefore cast doubt on priming effects of unconscious stimuli in CFS paradigms. We speculate that CFS operates at early levels of stimulus processing that provide the input for different processing streams like processing for perception and processing for action.

Keywords: priming, continuous flash suppression, masking, visibility, consciousness

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