Supplementary Material for the manuscript

Low-level awareness accompanies "unconscious" high-level processing during continuous flash suppression

Abbreviated title: Priming and low-level awareness during CFS

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Appendix 1 - Awareness of color and location of suppressed faces

Before examining the involvement of lower-level awareness in the processing of higher-level features of suppressed stimuli, we first sought to verify that such lower-level awareness of color and location during CFS indeed exists beyond simple stimuli (Hong & Blake, 2009; Zadbood et al., 2011), and apply to faces.

Materials and Methods

Subjects

Eighteen healthy subjects with normal or corrected-to-normal vision (10 males, 17 right-handed and 14 right eye dominance), aged 18-35 (M = 23.9) participated in the experiment. We defined an exclusion criterion of at least 20 trials in each condition to get reliable data across trials, leading to the exclusion of one subject who had less than 20 trials with visibility 1 ratings. This experiment is an extension of the Hong and Blake (2009) study which reported robust effects even with very small sample size (n=6), thus we aimed at a double sample – 12 subjects in each version of the experiment (color and location) – and stopped data collection when we reached this number. The experiment –

and all others described here – conformed to institutional guidelines for experiments with human participants and to the declaration of Helsinki. All subjects gave written informed consent to participate in the experiment for monetary compensation.

Stimuli and apparatus

The apparatus was identical to the one described in experiments 1 and 2 in the main text. Face images depicted twenty males and twenty females who were famous people from another country (Israel), so that they were unknown to the subjects. All faces were matched for average luminance using the SHINE toolbox (Willenbockel et al., 2010).

Procedure

The experiment included a color and a location version. Each version started with a training session, and was followed by a low-level and a high-level visibility session. Faces were presented in an upright or inverted orientation, either colored in blue or green at the center of the screen (6.8° x 4.3°; color condition), or in grayscale, at either the right or left side of a white fixation cross (4.7° x 3.1°; location condition). Trial types were pseudo-randomly selected in each trial with the constraint that no more than 4 successive trials of the same orientation, the same gender or the same color/location would occur. In all sessions, trials were self-paced, and began with the presentation of a small black square and white frame of matched size to the left and right eye, respectively, at the fovea. Participants moved the frames to reach binocular fusion, so that the small square would fit into the frame. Then, a face was presented to the non-dominant eye, and dynamically changing CFS patterns, composed of random size grayscale circles, were presented to the dominant eye at 10Hz (Figure S1A; subjects' eye dominance was assessed by asking them to point at a distant target, cover each one of their eyes and report when they had experienced a stronger visual shift; (Miles, 1929)). The contrast of the suppressed face was linearly ramped-up to the maximal contrast (set individually for each subject) over 1s, and stayed at its maximal value for the rest of the presentation time. In the color condition, faces' edges were blurred by a convolution with a squared Gaussian elliptical mask ($\sigma 1$=quarter of face width, $\sigma 2$=half of face height).

Training session

The training session included one block of 40 trials, in which subjects were encouraged to report faces' color/location as soon as they detected it. Feedback was given to elevate subjects' confidence in their judgments. Faces were presented until subjects indicated their color/location by pressing the left/right button and disappeared after 10s if no response was given.

Low-level visibility session

This session included three blocks of 40 trials. CFS stimulation was identical to the training session. Subjects pressed the left/right button to indicate the face's color/location as soon as they detected it, and held the button until they saw any part of the face. They were specifically instructed not to wait until perceiving the entire face, but to report upon seeing any part of it by immediately releasing the button (Figure S1A). Upon button release, the image disappeared and subjects indicated how much of the face they saw when they first pressed the button (color/location categorization time) on a 4-level visibility scale (1: no experience of the face; 2: brief glimpse; 3: part of the face; 4: entire face). In case no button was pressed after 10s, the trial was aborted and discarded from the analysis (8.3% of total trials for color and 6.3% for location).

High-level visibility session

The high-level visibility session included three blocks of 40 trials. CFS stimulation was identical to low-level visibility session, but was stopped immediately when subjects reported faces' color/location (Figure S1B). Subjects then performed two additional tasks that served as objective measures for the level of processing of the faces: they classified the face as upright/inverted and as male/female. Subjects were instructed to guess if they did not know the answer. The order of these two questions was counter-balanced across subjects. Finally, subjects again rated the visibility of the suppressed face at the time they reported seeing the color/location on a 4-level scale.

Results

Awareness of color of suppressed faces

On average, 43% (SD = 15) of trials were rated with visibility 1, 32% (SD = 12) with visibility 2, 19% (SD = 8) with visibility 3, and 8% (SD = 6) with visibility 4. Subjects detected color with high accuracy for all visibility levels, that is, on almost all trials (visibility 1: M = 86%, SD = 8%, 95% CI [81 90]; visibility 2: M = 97%, SD = 3%, 95% CI [95 99]; visibility 3: M = 99%, SD = 2%, 95% CI [98 100]; visibility 4: M = 100%, SD = 0%, 95% CI [100 100]; red circles in Figure S2B, left panel. Error trials were excluded from all subsequent analyses (7.0% of total trials)). Averaged color categorization time was 2.41s (SD = 0.89s, 95% CI [2.16 2.67]) after stimulus onset, independent of subjective visibility (one-way ANOVA on categorization time with visibility as a within-subject factor: $F(1,11) = 0.33$, $p = 0.58$; partial $\eta^2 = 0.03$). To evaluate the duration of low-level awareness as a function of stimulus visibility at the time of color categorization, we computed the time difference between color categorization (button press) and perceiving any part of the face (button release). A one-way ANOVA of this duration with visibility (1-4 ratings) as a within-subject factor revealed that low-level awareness duration decreased with visibility ($F(1,11) = 43.23$, $p < 0.0001$, partial $\eta^2 = 0.78$: visibility = 1; 43% of trials, M = 3.62s, SD = 1.55s, 95% CI [2.75 4.50]; visibility 2: 32% of trials, M = 1.73s, SD = 1.00s, 95% CI [1.16 2.30]; visibility 3: 19% of trials, M = 0.68s, SD = 0.38s, 95% CI [0.47 0.89]; visibility 4: 6% of trials, M = 0.46s, SD = 0.35s, 95% CI [0.23 0.68], left panel in Figure S2A).

One could claim that the time difference between detecting the color and perceiving the face reflects the instruction to press the button upon seeing the color, and then release it when seeing the face. This claim can be addressed in two ways. First, we specifically instructed subjects to refrain from holding the button when they perceived the face before or concurrently with the color (e.g., press and immediately release, as was done in visibility 3 and 4 trials). Notably, when we debriefed subjects after the experiment, none said they perceived any part of the face prior to the color, only at the same time or later. Second, in Hong & Blake's (2009) study, subjects used two buttons to report color and orientation, and time differences between the two percepts were similar to the ones we found.

Importantly, subjects' performance in the separate test for orientation and gender categorization (in which the display was removed immediately after color categorization), was at chance for visibility 1 trials both in the orientation task (blue, left panel in Figure S2B; M = 49%, SD = 9%, $t(11) = -0.20$, $p = 0.84$, 95% CI [44 55]) and in the gender task (green, left panel in Figure S2B; M = 53%, SD = 7%, $t(11) = 1.47$, $p = 0.17$, 95% CI [48 57]). Paired t-tests showed that color categorization was better than both orientation and gender categorization (orientation: $t(11) = 7.28$, $p < 0.001$; gender: $t(11) = 7.30$, $p < 0.001$). Analyses of variance on subjects' accuracy with visibility as a within-subject factor revealed that both orientation ($F(3,32) = 42.13$, $p < 0.0001$, partial $\eta^2 = 0.78$) and gender categorization ($F(3,32) = 25.15$, $p < 0.0001$, partial $\eta^2 = 0.70$) gradually increased with visibility (visibility 2: orientation: M = 76%, SD = 16%, $t(11) = 5.56$, $p < 0.001$, 95% CI [65 86]; gender: M= 65%, SD = 17%, $t(11) = 3.07$, $p = 0.01$, 95% CI [54 75]; visibility 3: orientation: M = 92%, SD = 9%, $t(11) = 16.07$, $p < 0.001$, 95% CI [86 98]; gender: M = 84%, SD = 12%, $t(11) = 9.91$, $p < 0.001$, 95% CI [77 92]; visibility 4: orientation: M = 93%, SD = 16%, $t(10) = 8.83$, $p = 0.001$, 95% CI [82 100]; gender: M = 92%, SD = 16%, $t(10) = 8.73$, $p < 0.0001$, 95% CI [81 100]; all t-tests compared performance to 50%). To accurately estimate the effect size of this gradual increase, we performed a linear regression between visibility levels and the duration of partial awareness for individual subjects, and found adjusted R^2 values of 0.85 (SD = 0.14).

Awareness of location of suppressed faces

On average, 33% (SD = 12) of trials were rated with visibility 1, 36% (SD = 10) with visibility 2, 22% (SD = 9) with visibility 3, and 10% (SD = 9) with visibility 4. Again, subjects detected location with relatively high accuracy (visibility 1: M = 77%, SD = 12%, 95% CI [70 85]; visibility 2: M = 97%, SD = 6%, 95% CI [94 100]; visibility 3: M = 99%, SD = 3%, 95% CI [97 100]; visibility 4: M = 99%, SD = 3%, 95% CI [96 100]; red, right panel in Figure S2B. Akin to the color condition, error trials were excluded from all subsequent analyses (8.7% of total trials). Averaged location categorization time was 2.01s (SD = 1.26s, 95% CI [1.65 2.37]) after stimulus onset and was independent of stimulus visibility level ($F(1,11) = 0.673$, $p = 0.43$, partial $\eta^2 = 0.06$: visibility 1, 33% of trials, M = 2.28s, SD = 1.44, 95% CI [1.45 3.09]; visibility 2, 36% of trials, M = 1.88s, SD = 1.00, 95% CI [1.31 2.45]; visibility 3, 22% of trials, M = 1.91s, SD = 1.21, 95% CI [1.22 2.59]; visibility 4, 9% of trials, M = 1.95s, SD = 1.47, 95% CI [1.08 2.82]). A one way ANOVA of the duration of low-level awareness with visibility (1-4 ratings) revealed that duration decreased with visibility ($F(1,11) = 34.22$, $p < 0.001$, partial $\eta^2 = 0.86$: visibility 1: M=2.74s, SD = 1.16s, 95% CI [2.28 3.40]; visibility 2: M = 1.59s, SD = 0.88s, 95% CI [1.09 2.08]; visibility 3: M = 1.01s, SD = 0.69s, 95% CI [0.63 1.40]; visibility 4: M = 0.44s, SD = 0.24s, 95% CI [0.30 0.58]; right panel in Figure S2A), similar to the color condition. Low-level awareness durations in visibility 1 trials were similar in the color and location conditions ($t(20.44) = -1.58$, $p = 0.13$).

Here, subjects' performance on both orientation and gender categorization was above chance for visibility 1 trials (blue and green, respectively, right panel in Figure S2B; orientation: M = 66%, SD = 13%, $t(11) = 4.28$, $p = 0.001$, 95% CI [58 74]; gender: M =

59%, SD = 14%, t(11) = 2.37, $p = 0.04$, 95% CI [51 68]), suggesting that when subjects were aware of the faces' location, they also had access to some information about the orientation and gender. Paired t-test comparing location categorization with orientation and/gender categorization for visibility level 1 revealed that the latter were lower than the former (orientation: t(11) = 2.89, $p = 0.01$; gender: t(11) = 4.42, $p = 0.001$). Similar to the color condition, an ANOVA revealed that both orientation ($F(3,31) = 39.05$, $p < 0.001$, partial $\eta^2 = 0.79$) and gender categorization ($F(3,31) = 42.39$, $p < 0.0001$, partial $\eta^2 = 0.80$) gradually increased with visibility (visibility 2: orientation: M = 89%, SD = 9%, t(11) = 14.32, $p < 0.001$, 95% CI [83 95]; gender: M = 81%, SD = 11%, t(11) = 10.24, $p < 0.001$, 95% CI [75 88]; visibility 3: orientation: M = 98%, SD = 3%, t(11) = 47.83, $p < 0.0001$, 95% CI [96 100]; gender: M = 93%, SD = 8%, t(11) = 18.37, p < 0. 001 95% CI [88 99]; visibility 4: orientation: M = 97%, SD = 8%, t(9) = 18.71, $p < 0.001$, 95% CI [91 100]; gender: M = 100%, SD = 1%, t(9) = 164, $p < 0.001$, 95% CI [99 100]; all t-tests compared performance to 50%). To accurately estimate the effect size of this gradual increase, we performed a linear regression between visibility levels and the duration of partial awareness for individual subjects, and found adjusted R^2 values of 0.81 (SD = 0.17).

Discussion

Here we showed that subjects can have conscious access to low-level features (color and location) of suppressed faces a few seconds before any other feature of these faces is consciously perceived. The longest separation in time between awareness of lower-level and higher-level features (~3 s) was obtained in trials where subjects indicated detecting the color/location while having no experience of the face (visibility 1 trials, that constituted 44% of the trials in the color condition and 31% in the location condition). The visibility tests in the color condition showed that despite having relatively high performance for color, subjects had no access to faces' orientation or to their gender (though above chance performance was found in the location condition).

These findings substantiate the claim that CFS does not always render all features of the stimuli invisible, but rather allows for differential access to some features, while suppressing others. It extends previous reports (Hong & Blake, 2009; Zadbood et al., 2011) by showing that this occurs not only for simple stimuli like shapes or gratings, but also for complex ones, like faces. This enabled us to examine the relations between awareness of low-level features and high-level processing during CFS in Experiments 1 and 2.

Appendix 2 – An alternative prime visibility test

In Experiments 1 and 2, we found face identity priming only on confidence 2, where subjects detected color with relatively high accuracy. Importantly, in these trials, subjects were at chance for prime fame categorization, suggesting that they were unaware if the prime was famous or not. However, this prime visibility test can be criticized for not probing the critical feature that drives the priming effect (i.e., repetition between the identity of prime and target), as subjects were not asked to report prime identity but only to categorize it.

In order exclude the option that the priming we found was based on some awareness of the prime's identity rather than fame, we conducted two control studies, each with twelve naïve participants with similar characteristics to the subjects of Experiments 1 and 2. The procedure of this studies followed that of Experiments 1 and 2 (respectively), including a training session, threshold setting using performance on the priming task, and the actual experiment (though subjects only completed 3 blocks out of the 14 blocks of the original experiment), however the prime visibility test was different: instead of asking about prime fame, here two faces of the same category (i.e., either famous or unknown) and gender were presented, and subjects were asked to determine which one was presented as prime.

Control Study 1 – Color Experiment

Akin to the results of Experiment 1, Confidence 1 trials coincided with a low, but significantly higher than chance-level performance for color categorization ($M = 60.9\%$ [54.4 67.5], $t(11) = 3.29$, $p = 0.008$ (here and elsewhere, tested against 0.5)). Confidence 2 trials ("I think I know the color") corresponded with a much higher performance ($M = 80.3\%$ [71.9 88.9], $t(11) = 7.03$, $p < 0.001$). Crucially, participants were unable to detect which of the two faces was the prime, neither in confidence 1 trials ($M = 49.9\%$, $t(11) = -0.02$, $p = 0.98$), nor in confidence 2 trials ($M= 51.1\%$, $t(11) = 0.92$, $p = 0.38$; paired sample t-test between confidence levels: $t(11) = -0.31$, $p = 0.76$).

Control Study 2 – Location Experiment

Control study 2 yielded similar results to those of Control study 1. Confidence 1 trials coincided with a low location performance ($M = 51.0\%$ [47.5 54.6], $t(11) = 0.58$, $p = 0.58$), while in confidence 2 trials, performance was much higher ($M = 80.9\%$ [74.1 87.7], $t(11) = 8.87$, $p < 0.001$). Here again, participants were unable to detect the prime face, neither in confidence 1 trials (M = 49.9%, t(11) = - 0.61, p = 0.56), nor in confidence 2 trials (M= 54.3%, t(11) = 1.72, p = 0.11; paired sample t-test between confidence levels: t(11) = -1.90, p = 0.08). Taken together, these results confirm that participants were not conscious of the critical dimension underlying the priming affect (i.e., prime identity).

Supplementary Figures and Figure Legends

Figure S1

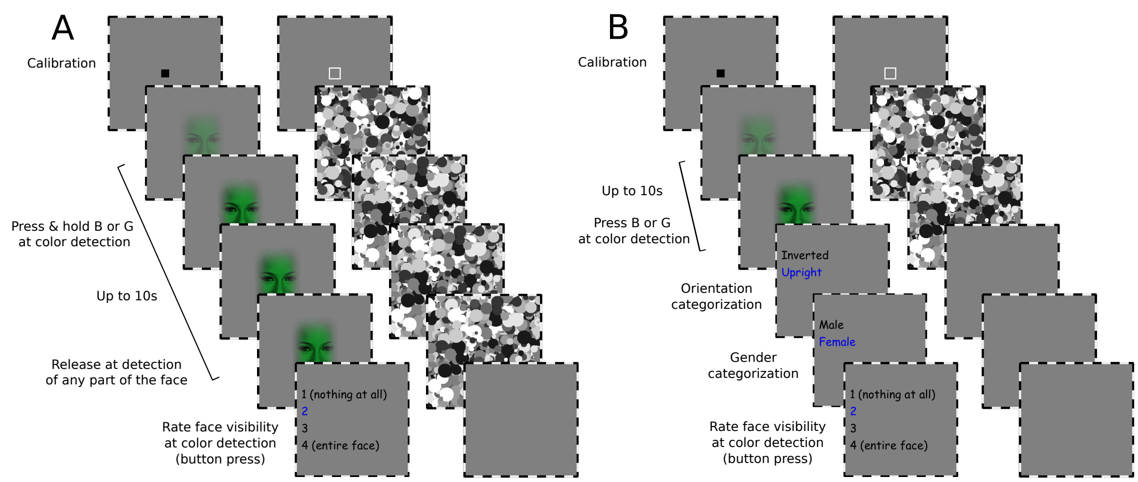

Figure S1: *Experimental paradigm.* **(A)** low-level awareness of color and location of suppressed faces. After calibration, CFS patterns were flashed to the dominant eye at 10Hz while the contrast of a green/blue colored unknown face, presented at the center of the visual field, was ramped up in the non-dominant eye over 1s. Subjects had to press and hold the B (blue) or G (green) buttons as soon as they detected the color, and release it as soon as they detected any part of the face. Stimulation disappeared at button release (or after 10s if no button press/release was made). Subjects had to rate the visibility of the face at the time of color categorization on a 4-level scale ranging from 1 ("didn't see anything of the face") to 4 ("saw the entire face"). In the location version of the experiment, faces were grayscale and appeared to the right or the left of a fixation cross. (B) Face visibility test (measured in a separate condition). Here, stimulation disappeared at button press and subjects had to categorize the orientation and gender of the face (order of questions was counter-balanced between subjects). Then they were asked to rate the visibility of the face at the time of color/location categorization on the 4-level scale.

Figure S2

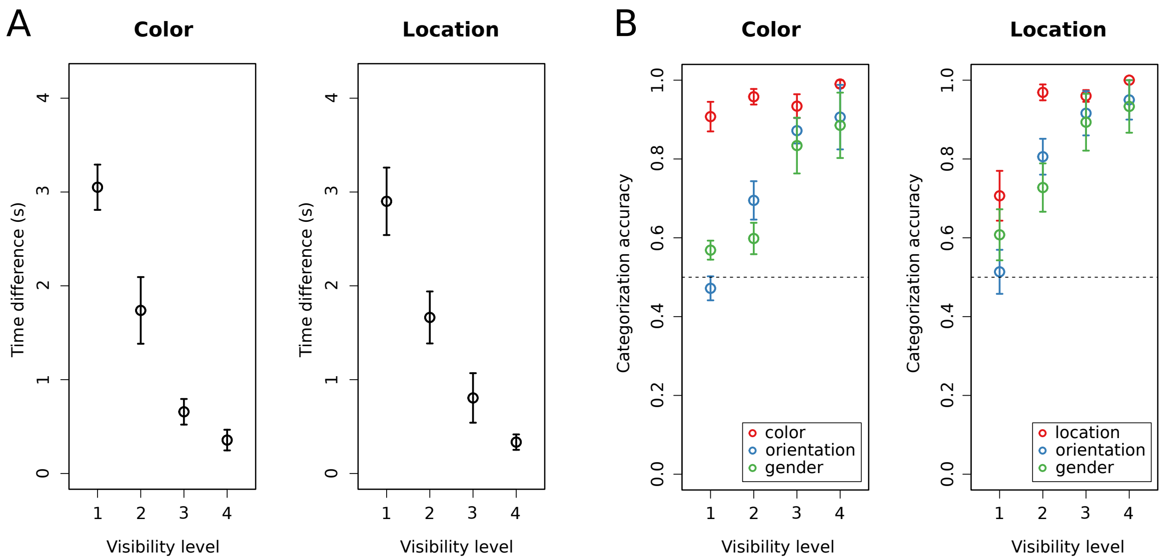

Figure S2: *Time difference between low-level awareness of color or location and a conscious percept of any part of the face*. **(A)** Average time difference between button press (categorization of color/location) and button release (perception of any clear part of the face) for the four face visibility levels upon categorization of color/location (1 = "didn't see anything of the face" to 4 = "saw the entire face"), in the color (left) and location (right) conditions. Notably, for visibility level 1 trials, part of the face was consciously perceived about 3s later than perception of color/location. **(B)** Average accuracy on the color/location (red), upright/inverted (blue) and gender (green) categorization tests for the four visibility levels. Importantly, accuracy at visibility level 1 is high for color/location test but around chance for the orientation and gender tests. That is, subjects were not aware of the face, nor its orientation, even though they could accurately detect its color or location. Error bars denote SEM.