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Conscious awareness is necessary for affective faces to influence social judgments

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ABSTRACT

A growing body of research claims that stimuli presented outside conscious awareness can influence affect, speech perception, decision-making, eating behavior, and social judgments. However, research has shown that conscious awareness is a continuous phenomenon. Using a continuous flash suppression (CFS) paradigm to suppress awareness of affective faces (smiling and scowling), we demonstrate that some awareness of suppressed stimuli is required for the stimuli to influence social judgments. We discovered this using a rigorous within-participants psychophysics method that allowed us to assess awareness at very low levels, which is difficult using traditional methods. Our findings place boundary conditions on claims (made previously by us and others) that stimuli presented completely outside conscious awareness influence judgments. This work contributes to the literature highlighting the need to study conscious awareness as a continuous phenomenon and provides a framework for researchers to ask and answer questions regarding conscious awareness and its relation to judgment and behavior.

1. Introduction

Many researchers (including us) have claimed that stimuli presented outside conscious awareness can influence diverse phenomena such as affect (Li, Zinbarg, Boehm, & Paller, 2008), speech perception (Plass, Guzman-Martinez, Ortega, Grabowecky, & Suzuki, 2014), decision-making (Vlassova, Donkin, & Pearson, 2014), eating behavior (Winkielman & Berridge, 2004), and social judgments (Anderson, Siegel, White, & Barrett, 2012). However, several barriers limit the interpretability of experiments claiming to measure the effects of stimuli presented outside conscious awareness (for a review, see Yang, Brascamp, Kang, & Blake, 2014). For example, studies are often underpowered to measure very low levels of awareness, and individual differences in perceptual abilities are rarely considered. Therefore, group-level effects might depend on a small number of participants who have non-zero awareness that goes undetected. In addition, most studies dichotomize perceivers as "aware" or "unaware" which is overly simplistic because conscious awareness is better described as a continuous phenomenon (e.g., Pessoa, Japee, & Ungerleider, 2005; Rouder & Morey, 2009; Tamietto et al., 2015). Thus, although research in this area typically asks: *Can a stimulus influence a phenomenon of interest even when people have no awareness of the stimulus?*, two more productive questions are: (1) *How does the influence of a stimulus on a phenomenon of interest vary with changes in an individual's awareness of the stimulus?*, and (2) *Are there individual differences in the relationship between stimulus intensity and the phenomenon of interest?*

To address these questions, we combined a social judgment task that we have previously used (Anderson et al., 2012; Siegel, Wormwood, Quigley, & Barrett, 2018) with a rigorous idiographic psychometric curve fitting approach adapted from vision science in which each participant completes hundreds of trials across a wide range of stimulus intensities (here, image contrast level) (e.g., Sandberg, Bibby, Timmermans, Cleeremans, & Overgaard, 2011). This approach provides sufficiently powered within-person data to treat awareness and social

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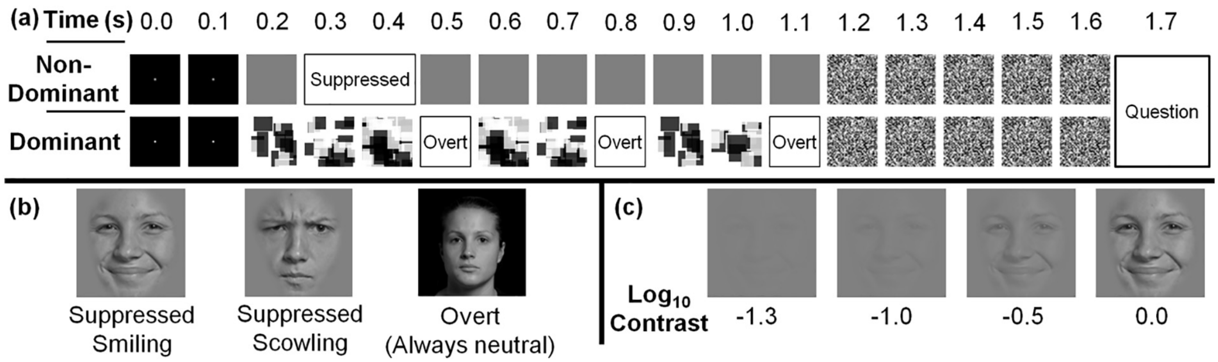

Fig. 1. Each CFS trial presented a sequence of images to each eye wherein the face images had a particular expression and contrast level. (a) Different images were shown to the dominant and non-dominant eyes. The images included a fixation dot, a gray square, Mondrian style patterns, a suppressed face, an overt face, random white noise images for backwards masking, and a question (e.g., asking whether the participant saw the suppressed face: yes/no). For the Face Detection task, a "No CFS" condition presented the suppressed face at maximum contrast to both eyes from 0.3 to 0.5 s. (b) The suppressed face was a close-up face with a smiling or scowling expression and the overt face had a neutral expression. The tasks used fifty different identities (25 male, 25 female; but only one identity is shown here). The suppressed and overt face always had the same identity. (c) The suppressed face spanned $\log_{10}$ contrast levels from −1.3 to 0, wherein −1.3 is nearly invisible and 0 is maximum contrast.

judgment (our phenomenon of interest) as continuous variables. Moreover, this approach can map relationships among these variables by comparing changes in each variable along a single, shared dimension: stimulus intensity. A major advantage of this idiographic psychometric curve fitting approach is that it allows us to extrapolate results to very low levels of awareness that are difficult to manipulate and measure directly.

In each of two tasks, we reduced awareness of visual stimuli using continuous flash suppression (CFS; Tsuchiya & Koch, 2005), wherein rapidly changing high-contrast images are presented to one eye to suppress awareness of a single, image presented simultaneously to the other eye (e.g., Fig. 1a). Specifically, we presented overt neutral faces—which participants consciously saw—amid a series of high-contrast patterned images to the participants' dominant eye while simultaneously presenting smiling or scowling faces of varying contrast levels—which were suppressed from awareness to varying extents—to the non-dominant eye. In the first task, participants reported whether they detected each suppressed face (yes/no; *a binary rating of awareness*) and rated how clearly they saw the face (*a continuous rating of awareness*). In the second task, participants reported their willingness to approach or avoid each overt neutral face (*a measure of social judgment*). We analyzed each participant's relatively large dataset using psychometric curve fitting. To our knowledge, this is the first study to employ such a rigorous approach to examine continuous relationships between awareness of affective social stimuli and their influence on social judgments. By establishing this method within the context of CFS and a social judgment task for which our group already has expertise, future work can continue this line of work to address more specific and nuanced scientific questions and other tasks besides social judgment.

2. Materials and methods

2.1. Participants

Because this project was the first of its kind, it was not possible to use traditional power analyses to determine sample size. Therefore, sample size was determined by our resources (5–10 participants per semester for two years) and we performed one interim analysis that did not influence the sample size. We reasoned that running 20–40 participants would provide ample power considering that parametric studies in vision science often employ very few participants (e.g., $N = 18$ from (Mudrik, Breska, Lamy, & Deouell, 2011), $N = 11$ from (Pessoa et al., 2005), $N = 1$ from Tamietto et al., 2015). Fortunately, using effect size estimates from the current project, future studies can use traditional *a priori* power analyses to determine the number of participants, trials, contrast levels, etc.

Thirty-nine participants (31 females; age range 19–29 years) were recruited from the Interdisciplinary Affective Science Lab at Northeastern University, United States. Laboratory members were recruited because they were more willing and able to complete this lengthy study compared to a typical student or community sample. Of these 39 participants, 25 participants completed the entire study (attrition was caused by personnel turnover in the lab). We removed data from two additional participants from all analyses: one due to an error in stimulus presentation, and one because all the stimulus intensities were too low for detection. Thus, the final dataset consisted of 23 participants (17 females, 19–25 years old), all of whom were blind to the study's hypotheses.

With 23 participants, sensitivity analyses ($\alpha = 0.05$ two-tailed, and $1\text{-}\beta = 0.8$) indicate that we can detect across-participant effects as small as Cohen's $d = 0.61$ using a paired t-test (Faul, Erdfelder, Lang, & Buchner, 2007) (e.g., compare average awareness levels at two different contrasts across participants, compare average judgment ratings for smiling vs. scowling faces across participants). Thus, we are sufficiently powered to detect effects smaller than were found in a prior study using a similar task comparing social judgments of neutral faces when paired with suppressed smiling vs. scowling faces (Study 3, Trustworthiness ratings, Cohen's $d = 1.06$; Anderson et al., 2012).

2.2. Experimental tasks

In these studies, we report all measures, manipulations and exclusions. Participants completed two separate tasks, a Face Detection task and a Social Judgment task. Both tasks used the same stimuli and timing described herein (Fig. 1). To reduce awareness of certain visual stimuli, we utilized an established suppression paradigm, CFS (Tsuchiya & Koch, 2005), wherein rapidly changing high-contrast images are presented to a participant's dominant eye in order to partially suppress awareness of a single image presented simultaneously to the participant's non-dominant eye. For simplicity hereafter, we use the term *suppressed face* to refer to stimuli that we attempted to suppress using CFS. As our results indicate, CFS either partially or completely suppressed the faces to varying extents, depending on the contrast of the suppressed face. For each trial of both tasks, participants were presented with a neutral face embedded in a series of high-contrast Mondrian images to their dominant eye, such that participants could consciously see the neutral face (which we call the overt face). Also on each trial, an affective face (smiling or scowling) was presented to the non-dominant eye slightly preceding the overt face. The affective face was partially suppressed from awareness using CFS (i.e., the stimulus timing in Fig. 1). The suppressed affective faces were slightly larger than the overt neutral faces to prevent the two faces from fusing into a single percept. Per our psychometric approach, we varied the contrast of the suppressed affective faces across trials, yielding different levels of suppression across trials. We also included "blank" trials, where a gray square was presented instead of a suppressed affective face, and "No CFS" trials, where the suppressed affective face was presented at maximum contrast to both eyes.

2.2.1. Face detection task

In the first task, designated Face Detection, participants were instructed that on each trial they would be shown a series of flashing patterns (the Mondrian images) and either one or two faces: always the overt face—which appears 3 times—and sometimes the suppressed face, as well. The instructions specified that some trials would show a face that is "hard to see" (the suppressed face) that would appear before the overt face and would be larger than the overt face. After each trial, participants were asked whether they saw the suppressed face and they responded with their left hand using two keys on the keyboard labeled "yes" and "no". We call this response the *binary rating of awareness*. Next, participants were asked to rate their awareness of the suppressed face, and they responded using a mouse on a continuous slider scale anchored at "No experience" (0.0) to "Intermediate" (0.5) to "Clear experience" (1.0), adapted from Ramsøy and Overgaard (2004). If participants reported not seeing the face on a given trial, they were instructed to report "No experience" on the slider scale. We call this response the *continuous rating of awareness*. See Supplemental Online Material for the verbatim task instructions.

2.2.2. Social judgment task

The Social Judgment task was designed to assess how the expressions of the suppressed affective faces influenced approach/avoid judgments of the overt neutral faces. The Social Judgment task was identical to the Face Detection task except for the instructions before the task and the questions asked on each trial. Participants were instructed that in everyday life people regularly decide to approach or avoid other people based on limited information, and that these approach/avoid decisions can be based on subtle "gut feelings" that fluctuate from moment to moment. Participants were told they would view a series of flashing patterns (Mondrian images) and either one or two faces: the overt neutral face presented 3 times and sometimes a suppressed face, as well. Participants were asked to report whether they would approach or avoid the overt face based only on what they saw in the trial. Participants responded using a mouse on a continuous slider scale anchored at "Avoid" (0.0) to "Stay neutral" (0.5) to "Approach" (1.0). See Supplemental Online Material for the verbatim task instructions.

Both Face Detection and Social Judgment tasks were implemented using an in-house MATLAB program (MathWorks, Natick, MA) that utilized the PsychToolbox extensions (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997). Image contrast of the suppressed affective faces was set using the *imadjust* function in MATLAB, such that images with lower contrast values appeared more gray (Fig. 1c). For both tasks, 50 different identities were used: 25 males and 25 females from the IASLab Face Set (http://www.affective-science.org). For each trial, the identity of the overt neutral face and the suppressed affective face were the same. For the Face Detection task, participants completed 800 trials that crossed eight contrast levels (including blank and "No CFS") and two suppressed expressions (smiling and scowling) for each of the 50 identities. For the Social Judgment task, participants completed 700 trials that crossed seven contrast levels (including blank) and two suppressed expressions (smiling and scowling) for each of the 50 identities.

An initial set of participants completed more trials and contrast levels as well as an additional task that was completed between Face Detection and Social Judgment that was not relevant to the present investigation (See Supplemental Online Material); the data from this additional task are not discussed here.

2.2.3. Procedure

At the start of their first session, we greeted participants and obtained written informed consent in accordance with the Institutional Review Board of Northeastern University. Next, participants completed a demographics questionnaire. Because suppression of images under CFS is more easily achieved when the suppressed images are presented to the non-dominant eye, we assessed ocular dominance using the Dolman Method (Dolman, 1919), see Supplementary Material. Participants were then given general instructions for the experiment, including an explanation that CFS can be used to suppress images from awareness and an introduction to the mirror stereoscope. Participants were told the goal of the study was to assess how well people can see suppressed faces under CFS.

Participants first completed the Face Detection task over the course of 1–65 days ($M = 24.0$, $SD = 19.6$ days). To minimize fatigue, trials were blocked into sessions of 150 trials each (approximately 15 min), and participants were given freedom to complete each task in a self-paced manner over as many laboratory sessions as they required. At least one day after completing the Face Detection task, participants began the Social Judgment task, which was completed over the course of 1–44 days ($M = 10.5$, $SD = 12.8$ days). We arranged for Face Detection to be completed first to enable a more conservative comparison between Face Detection and Social Judgment tasks in the event that, due to practice, participants were better at detecting the affective faces in the Social Judgment task compared to the Face Detection task.

During these tasks, participants sat in a dimly lit testing room with their head in a chin rest and viewed a computer monitor through a mirror stereoscope. Stimuli were presented at a size of 7 cm × 7 cm on a 43 cm LCD monitor placed 45 cm from the participant's eyes. The monitor is a Dell E178FP 17″ monitor with a resolution of 1280 × 1024 pixels, a refresh rate of 60 Hz, and an unspecified decay rate. At the start of each testing session, participants self-calibrated the mirror stereoscope and completed eight practice trials spanning several stimulus intensities. Practice trials were not analyzed.

2.3. Calculation of psychometric measures

2.3.1. Binary ratings of awareness

Using binary ratings of awareness during the Face Detection task, we calculated each participant's *sensitivity* (d') to detecting the suppressed faces at each contrast level x as: $d'(x) = \mathbf{Z}(FHits(x)) - \mathbf{Z}(FFalseAlarms)$, where $\mathbf{Z}(p)$ is the value of the standard normal distribution ($M = 0$, $SD = 1$) whose probability is p (p is either *FHits* or *FFalseAlarms*); $FHits(x)$ is the proportion of hits at contrast level x (number of "yes" responses at contrast x divided by the number trials at contrast x), and *FFalseAlarms* is the proportion of false alarms (number of "yes" responses across all blank trials divided by the number of blank trials; Green & Swets, 1966; Wickens, 2002). The measure of d' is independent of response bias, compared to a measure of accuracy such as percent correct. If a participant responded that they saw the suppressed face on every trial, their calculated d' value would be zero (i.e. no ability to discriminate between trials when the face is there vs. is not there).

2.3.2. Continuous ratings of awareness

We quantified participants' ratings of how clearly they saw the stimulus (ranging 0 to 1) during the Face Detection task (Ramsøy & Overgaard, 2004). To do so, we averaged the awareness responses across all 100 trials at each contrast level. If a participant responded that he or she did not see a suppressed face on a given trial, then the awareness response for that trial was set to zero.

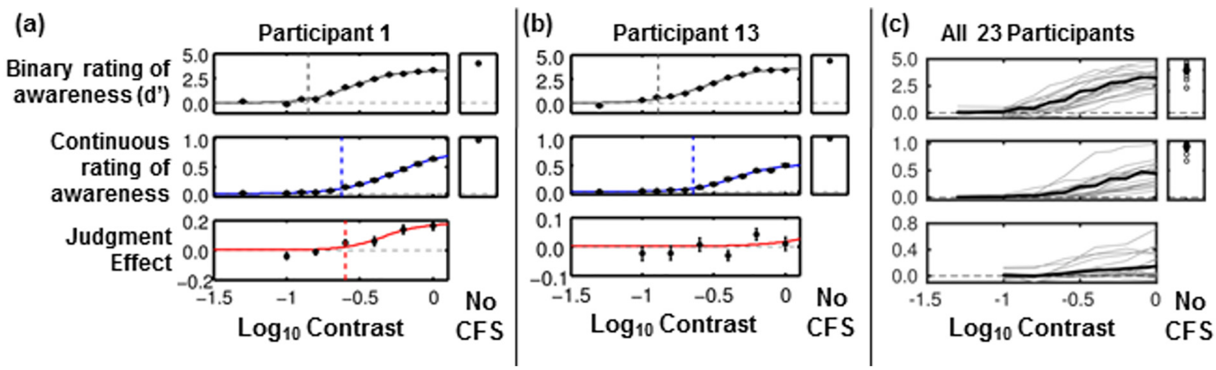

Fig. 2. Increasing the contrast of the suppressed affective face increased sensitivity (d') from binary ratings of awareness, continuous ratings of awareness, and—for nine out of the twenty-three participants—the judgment effect, which is the ability for the expression of the suppressed face to influence the approach/avoid judgments. (a) For participant #1, the judgment effect increased as contrast increased. That is, as contrast increased, participant #1 exhibited greater willingness to approach the neural face when paired with a suppressed smiling face (compared to when paired with a suppressed scowling face). (b) The judgment effect of participant #13 was not systematically influenced by the contrast of the suppressed face. Additional participants are shown in Fig. S1. Each data point is based upon 100 trials. The error bars show the standard error of the mean and some error bars may be smaller than the symbols. Each curve in parts (a) and (b) shows the fit to a sigmoid psychometric function and each vertical dashed line illustrates the rise point. (c) Each thin line shows results from one participant and the thick line shows the average across participants. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.3.3. Judgment effect

To assess our phenomenon of interest, whether the expression of the suppressed affective faces influenced social judgments, we subtracted the approach/avoid rating (ranging 0 to 1) when each overt face was paired with a suppressed scowling face from the approach/avoid rating when the same face was paired with a suppressed smiling face within each contrast level for each participant. These difference scores (ranging −1 to 1) were averaged over the 50 face identities at each contrast and this average difference score was designated the *judgment effect*. Higher judgment effect values indicate the participant's greater willingness to approach the overt face when paired with a suppressed smiling face versus when paired with a suppressed scowling face.

2.3.4. Curve fitting the psychometric measures

For each participant, we fit our three outcome variables (sensitivity (d') from binary ratings of awareness, continuous ratings of awareness, and judgment effect) vs. stimulus contrast to three corresponding psychometric functions. Because our psychometric data often exhibited a plateau toward the higher contrast levels, we selected a sigmoid ("S" shaped) psychometric function for all three variables: $Response(x) = a + ((b - a)/(1 + \exp((c - x)/d)))$, where x is the suppressed face contrast on a $\log_{10}$ scale, $Response(x)$ is the value at contrast x for the outcome variable, a is the lower limit of the psychometric function, b is the upper limit of the psychometric function, c is the center of the sloping region of the psychometric function, and d is the width of the sloping region of the psychometric function. We used nonlinear fitting with the *lsqcurvefit* function in MATLAB. See Supplementary Material for additional details.

3. Results

First, we report group-level analyses that reflect the traditional approach to data analysis in similar suppression paradigms. Next, we report results from our within-participants psychometric curve fitting analyses, which highlight the limitations of relying only on a group-level approach to assessing relationships between conscious awareness and a phenomenon of interest.

3.1. Group-level analyses

3.1.1. CFS reduced awareness of suppressed affective faces

Consistent with prior work (Tsuchiya & Koch, 2005), CFS effectively suppressed faces. Sensitivity (d') from binary ratings of awareness of the suppressed faces was higher when the faces were presented *without* CFS at maximum contrast (mean with 95% confidence interval = 3.97 [3.71, 4.24]) versus when they were presented *with* CFS at maximum contrast (M = 3.24 [2.95, 3.54]), paired samples mean difference 0.73 [0.50, 0.96] with effect size M/SD_{pooled} = 1.02. Similarly, continuous awareness was higher when the faces were presented *without* CFS at maximum contrast (M = 0.94 [0.91, 0.98]) versus when they were presented *with* CFS at maximum contrast (M = 0.44 [0.36, 0.52]), paired samples mean difference 0.50 [0.43, 0.58] with effect size M/SD_{pooled} = 2.61.

3.1.2. Suppressed affective faces influenced social judgments

Consistent with prior work (Anderson et al., 2012), group-level analysis found participants reported greater willingness to approach the overt neutral face when it was paired with a suppressed *smiling* face at maximum contrast under CFS (M = 0.53 [0.49, 0.58]) versus when it was paired with a suppressed *scowling* face at maximum contrast under CFS (M = 0.38 [0.34, 0.43]), paired samples mean difference 0.15 [0.06, 0.23] with effect size M/SD_{pooled} = 1.27. Moreover, this judgment effect was still demonstrated at a $\log_{10}$ contrast as low as −0.60: specifically, participants reported their willingness to approach the overt neutral face more when it was paired with a suppressed *smiling* face at $\log_{10}$ contrast = −0.60 under CFS (M = 0.51 [0.47, 0.55]) versus when it was paired with a suppressed *scowling* face at $\log_{10}$ contrast = −0.60 under CFS (M = 0.47 [0.44, 0.50]), paired samples mean difference 0.04 [0.01, 0.07] with effect size M/SD_{pooled} = 0.47. At this $\log_{10}$ contrast of −0.60, the binary ratings of awareness for smiling or scowling faces was d' = 1.19 [0.87, 1.50]. Because the effect size of the judgment effect was smaller than the effect size for awareness at each contrast level, there were no contrast levels for which the judgment effect was statistically significant yet the awareness task was not statistically significant. However, this does not exclude the possibility that another study with a less rigorous measure of awareness could incorrectly conclude zero awareness in a case where the judgment effect was shown to be non-zero.

3.1.3. Contrast influenced awareness and the judgment effect

We quantified changes in awareness and social judgment across stimulus intensities. Aggregate data in Fig. 2c show that, at the group-level, the contrast of the suppressed face was positively related to: (1) sensitivity d' from binary ratings of awareness of the suppressed face (top row of Fig. 2c), (2) continuous ratings of awareness of the suppressed face (middle row of Fig. 2c), and, most importantly, (3) the effect of the expression of the suppressed face on social judgments of the overt neutral face (i.e., the judgment effect; bottom row of Fig. 2c).

3.2. Within-participants analyses

The traditional group level analyses cannot address two critical questions that require a within-participants approach: (1) Does the expression of the suppressed affective face influence social judgments for *every* participant?, and (2) How does the influence of a stimulus on a phenomenon of interest vary with changes in an individual's awareness of the stimulus? We answered both of these questions using a within-participants curve fitting approach that treats sensitivity (d') from binary ratings of awareness, continuous ratings of awareness, and the judgment effect as phenomena that vary continuously with the contrast of the suppressed affective faces.

3.3. Individual differences in the judgment effect

First, for each participant, we examined whether the willingness to approach an overt neutral face was influenced by the expression of the suppressed affective faces (i.e., was the judgment effect non-zero at any contrast level?). To test this, we compared fits of the judgment effect vs. contrast data using either the sigmoid curve or a flat line of value zero (F-test using $\alpha = 0.05$; e.g., Motulsky & Christopoulos, 2003). A better fit to the sigmoid curve indicates the participant's willingness to approach the overt faces was influenced by the expression of the suppressed affective faces. Alternatively, a better fit to the flat line of value zero indicates no judgment effect for that participant. Despite group-level findings that the expression of the suppressed faces significantly influenced social judgments, the within-participants analyses revealed that the judgment effect occurred for only nine of the twenty-three participants (Table S1). We designate those nine participants "responders" whereas the remaining sixteen participants are designated "non-responders." For illustration, the bottom of Fig. 2a shows a responder and the bottom of Fig. 2b shows a non-responder. Our results suggest that five additional participants might be identified as responders provided higher stimulus intensities and/or more trials to reduce noise in the measurements (p values between 0.05 and 0.2; Table S1). These results highlight the importance of considering individual differences that are typically missed using group-level analyses alone.

3.3.1. Relationships between binary ratings of awareness, continuous ratings of awareness, and the judgment effect

To examine the relationships between awareness and the judgment effect for each participant, we compared "rise points" of the fits to the three psychometric functions: sensitivity (d') from binary ratings of awareness vs. contrast, continuous ratings of awareness vs. contrast, and judgment effect vs. contrast. We defined the rise point as the lowest contrast of the suppressed affective face that yields a small (12%) increase in the outcome variable (vertical dashed lines in Fig. 2 and Fig. S1). Mathematically, we used each participant's fitted psychometric curve and calculated $RisePoint = c - 2d$, where c is the stimulus contrast at the middle of the curve and d reflects the width (shallowness) of the curve. With this formula, the rise point is the contrast that yields an outcome measure 12% higher than the participant's lower limit. Because comparisons across rise points within participants could not be done using traditional parametric tests, we used 1000 iterations of a non-parametric within-participants Monte Carlo resampling statistic (see Supplementary Material). This type of test is very robust to differences in distribution shapes, and makes greater use of the information in the data compared to other non-parametric tests that use rank values.

These rise point comparisons revealed several interesting findings (Fig. 3; statistics in Table S2). For 22 of the 23 participants, the participant's rise point for *continuous ratings of awareness* was greater than his or her rise point for *sensitivity (d′) from binary ratings of awareness* (i.e., all but one data point are above the diagonal in Fig. 3a). Thus, not surprisingly, continuous ratings of awareness of the suppressed affective faces required a higher contrast level than binary ratings of awareness for nearly all participants. For seven of the nine responders, the participant's rise point for the *judgment effect* was greater than his or her rise point for *sensitivity (d′) from binary ratings of awareness* (i.e., most data points are above the diagonal in Fig. 3b). Importantly, this indicates that the judgment effect required a higher contrast level than binary ratings of awareness for nearly all responder participants. Most importantly, for six of the nine responders, the participant's rise point for the *judgment effect* was greater than his or her rise point for *continuous ratings of awareness* (i.e., most of the data points are above the diagonal in Fig. 3c). This indicates that for nearly all responder participants, the judgment effect required a higher contrast level than their lowest level of continuous ratings of awareness. This finding is not a function of a small sample size; indeed, a sample size of nine, while lower than most psychological studies that examine the effects of stimuli presented "outside of awareness", is, in fact, typical and acceptable in vision science for idiographic techniques like the one we used here (e.g. $N = 11$ from Sandberg et al., 2011). This finding is also not due to the order of the Face Detection and Social Judgment tasks and the possibility that participants were better at detecting the affective faces in the Social Judgment task compared to the Face Detection task. If participants improved detection abilities due to practice, then the rise points for the judgment effect would be reduced, thus making it harder to show (as we did) that the rise points for the judgment effect are higher than rise points for detection and awareness. Taken together, these findings demonstrate that the suppressed stimuli generally influenced the willingness to approach a neutral target face, but at a contrast levels high enough to produce detectable changes in both binary and continuous ratings of awareness of the suppressed stimuli.

3.3.2. Individual differences in responses to the suppressed face at a given contrast level

Finally, our analysis of rise points revealed large individual differences in both binary and continuous ratings of awareness of the suppressed affective faces at each contrast level. This is evident in Fig. 3 and Fig. S1, which both show that rise points differ widely across participants. For example, a $\log_{10}$ contrast level − 0.75 yields a substantial sensitivity (d') from binary ratings of awareness for participant #18 ($d' = 1.8$; Fig. S1), whereas participant #29 can barely detect the stimulus at the same contrast level ($d' = 0.1$; Fig. S1). This highlights the importance of selecting stimulus intensities separately for each participant, particularly in studies that use only one or two stimulus intensities (which is the norm in many CFS studies).

4. Discussion

Our findings confirmed that CFS successfully reduced awareness of the suppressed affective faces: CFS robustly reduced both continuous ratings of awareness and sensitivity (d') from binary ratings of awareness. Additionally, in group level analysis, the expression of the suppressed affective faces influenced social judgments of the overt neutral faces. A more detailed analysis found this finding was driven by 9 out of 23 participants showing this effect. That is, these 9 participants reported greater willingness to approach overt neutral faces when paired with a suppressed smiling face compared to a suppressed scowling face. By analyzing psychometric curves fit to each participant's data, however, we found that a suppressed stimulus did not have an effect on a social judgment unless the stimulus intensity was high enough to permit a detectable amount of awareness (both measured using sensitivity (d') or continuous ratings of awareness). This is not a null effect, as we demonstrated that the social judgment task worked as intended (i.e., social judgments of the faces were influenced by the expression of the faces). Moreover, there were statistically significant differences

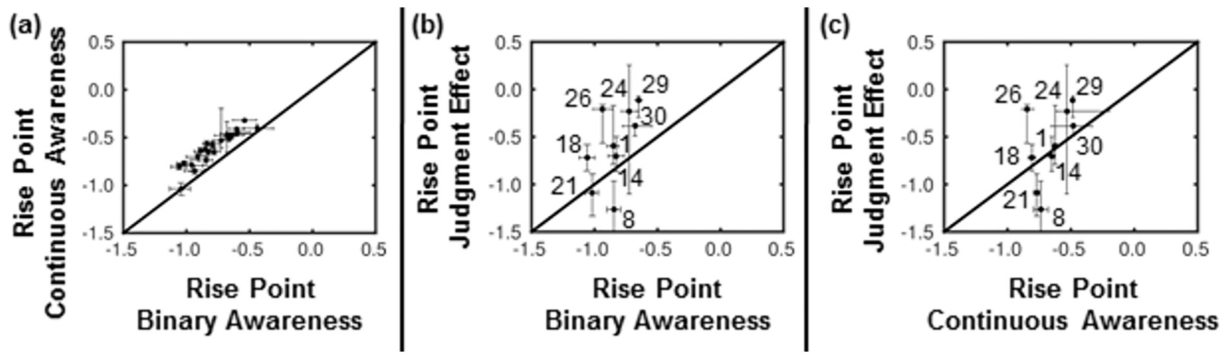

Fig. 3. The rise points for sensitivity (*d′*) from binary ratings of awareness, continuous ratings of awareness, and the judgment effect in $\log_{10}$ contrast units. Data points above the diagonal indicate the event on the y-axis required a higher suppressed face contrast than the event on the x-axis does to elicit a small effect (12% increase from its lower limit toward its upper limit). Error bars are 95% confidence intervals (full distributions in Fig. S2). Participant numbers are labeled in (b) and (c) only.

between the *relatively low* stimulus intensity required to elicit awareness of the faces and the *relatively high* stimulus intensity required for facial expressions to influence subsequent social judgments. This relationship applies to a wide range of stimulus intensities per our curve-fitting approach, as data at very low stimulus intensities are otherwise prohibitively difficult to measure and manipulate using traditional methods. Our results complement studies in other domains that also demonstrate awareness is required to elicit phenomena of interest such as semantic analysis (Kang, Blake, & Woodman, 2011) and autonomic arousal and attention (Hedger, Adams, & Garner, 2015). However, the present research moves beyond these prior studies by explicitly characterizing the continuous nature of awareness, in line with prior studies of perception (e.g., Pessoa et al., 2005; Sandberg et al., 2011; Tamietto et al., 2015).

The within-participants psychometric approach used here also revealed large individual differences that were not evident in the traditional group level analysis. For example, there were large individual differences in how a particular stimulus intensity influenced the effect of the suppressed faces on social judgments and the reported awareness of suppressed faces. These findings have important methodological implications; for example, studies that utilize only one or two stimulus intensities should select stimulus intensities separately for each participant to prevent certain participants from having too much or too little awareness of the stimuli. Additionally, considering our observation that only 9 of 23 participants were systematically influenced by the expression of the suppressed face, futures studies should consider collecting sufficient data to account for whether each participant in fact responds to the near-threshold stimuli. Despite these individual differences, however, we also note that the pattern within participants appears fairly consistent, with awareness occurring at a lower stimulus intensity than effects of social judgments.

A major strength of our study is the theoretically motivated design, which included (1) multiple stimulus intensities across distinct domains of stimulus processing: sensitivity (*d′*) from binary ratings of awareness, continuous ratings of awareness, and social judgment; (2) a large number of trials (nearly 2000 per participant); and (3) curve-fitting analyses to extrapolate results to very low levels of detection and awareness, which are prohibitively difficult to measure directly. Moreover, because each participant performed so many trials, we had sufficient statistical power to observe differences in rise points between sensitivity (*d′*) from binary ratings of awareness, continuous ratings of awareness, and social judgment effects for each individual participant. This is critical given our observation of large individual differences that preclude the use of traditional group-level analyses.

Although this study used several sophisticated methodological and analytic strategies, it has several limitations worthy of consideration for future work. First, we could not assess how awareness compared to the judgment effect for non-responders, as their social judgment responses were not systematically influenced by the expression of the suppressed face. Second, our results may be influenced the fact that the Face Detection task was always performed before the Social Judgment task. For example, if participants were more sensitive to the faces in the Social Judgment task than in the Face Detection task (from hundreds of trials of Face Detection) our results may reflect an under-estimation of the true effect size in terms of the difference in rise points between these two tasks. Such a bias would not change our conclusion that a small but detectable amount of awareness is generally required for a stimulus to influence social judgments. Future studies should address this possibility by acquiring data with task order counter-balanced across participants. Future studies should also consider Bayesian frameworks for design and analysis as used previously to study near-threshold effects (e.g., Overgaard et al., 2013). Finally, task instructions (Ansorge & Neumann, 2005) and the fact that our sample was laboratory members may have played a role in our findings, thus potentially limiting the generalizability of our results. However, our results showing successful stimulus masking using CFS is encouraging considering that our instructions and sample were likely minimize the effects of CFS—namely that subjects knew some trials would have suppressed stimuli even if they were hard to detect.

Now that we have established this psychometric curve-fitting method within this context, future studies can examine more specific and nuanced scientific questions (e.g., whether awareness of the facial expression of the suppressed face is related to the effects on subsequent social judgments) and can utilize traditional a priori power analyses to determine the number of participants, trials, contrast levels, etc. Future work should also address the extent to which our findings generalize to other phenomena beyond social judgments (e.g., eating behaviors, health behaviors, or threat detection) as well as to other suppression paradigms (e.g., backward masking, crowding, inattentional paradigms; for a review, see Kim & Blake, 2005) and other participant populations (e.g., individuals with social anxiety or schizophrenia). Finally, we need to understand the theoretical basis of individual differences in the association between stimulus awareness and its effects on judgments (e.g., understanding why some participants were "responders" and some were "non-responders"; Table S1). The ideographic approach used here is well-suited to such future investigations, and is consistent with theoretical perspectives positing in that individual differences should be examined as sources of meaningful information (i.e., signal variance) as opposed to discarded as sources of error or noise variance (Kanai & Rees, 2011).

5. Conclusions

Can stimuli presented outside of conscious awareness influence social judgments? Our results suggest that a small—but measureable—amount of awareness is required for a stimulus to influence social judgments. Importantly, the within-participants psychometric curve fitting approach used here affords enhanced precision and permits extrapolation to very low awareness levels that are otherwise prohibitively difficult to measure. Moreover, because this approach can be directly translated to other suppression paradigms and phenomena of interest, we have provided a potential methodological framework to both ask and answer more productive questions regarding the nature of conscious awareness and its relation to judgment or behavior.

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Conflict of interest

The authors declare no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jesp.2018.07.013.

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