**Non-conscious Perception of Facial Expression with Continuous Flash Suppression:
A Signal Detection Analysis**

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Abstract

The aim of this study is to explore if a conservative response criterion for facial expression perception during continuous flash suppression (CFS) is responsible for the differences between conscious and non-conscious perception. We hypothesized that the perception of facial expression in the absence of visual awareness under CFS represents non-conscious processing and is not a function of conservative criterion. We predicted that participants' sensitivity (d') in a detection task would be significantly lower than their sensitivity in a 2-alternative forced-choice (2AFC) task. After rendering images of faces with different facial expression (fearful vs. neutral) invisible for 500 milliseconds (ms) (Experiment 1) and 700 ms (Experiment 2) using CFS, participants judged the presence/absence of the faces with a yes/no detection task and the emotion of faces with the 2AFC task. Participants also rated their confidence on their detection and 2AFC responses. Our results indicate that when we rendered the face stimuli invisible for 500 ms, participants show residual ability to discriminate signal (fearful face) from noise (neutral face) by having a higher sensitivity in the 2AFC task as compared to the detection task. When we rendered the face stimuli invisible for 700 ms, the difference between participants' sensitivities in the two tasks disappeared. Therefore, non-conscious perception of facial expression with CFS might be time dependent even though CFS has the ability to suppress target stimuli from awareness for several seconds. These results provide additional evidence for the importance of using bias-free measures over the accuracy-based methods in visual consciousness research.

Keywords Visual consciousness, Non-conscious perception, Continuous flash suppression, Perceptual sensitivity, Signal detection theory

Introduction

The differences between conscious and non-conscious perception is an indispensable part of scientific understanding of conscious perception. By identifying and dissociating non-conscious processes from conscious processing, we will be able to better understand conscious perception in terms of behavioral and neural mechanisms. We can observe this dissociation across different conditions. For example, some people who are suffering from a lesion to the whole or a part of the primary visual cortex (V1) report that they cannot detect a visual stimulus within a scotoma (blind field). Despite the absence of conscious perception within the scotoma, these people are able to discriminate different attributes of the target stimuli (e.g. orientation or motion) at above chance level in a m-alternative forced-choice (m-AFC) task (Cowey, 2010; Weiskrantz, 1986, 1996; Weiskrantz, Barbur, & Sahraie, 1995). This condition is called blindsight, and people with blindsight show a clear dissociation between conscious and non-conscious perception.

Cheesman and Merikle (1984, 1986) suggested that differences between conscious and non-conscious perception are the result of the difference between subjective and objective threshold, which are applied to the same underlying sensory evidence (Figure 1). Cheesman and Merikle assert that the subjective threshold requires higher stimulus energy than the objective threshold. If the stimulus intensity exceeds the subjective threshold, an observer consciously perceives the stimulus. The observer, on the other hand, might respond in a non-conscious manner to stimuli when its intensities fall between the subjective and objective thresholds. Finally, the observer cannot respond to stimuli with an intensity lower than the objective threshold (in either a non-conscious or a conscious manner; Cheesman & Merikle, 1984, 1986).

Fig. 1 Subjective and Objective Thresholds.

To evaluate conscious perception, researchers may use a subjective detection (Yes/No) task. A “Yes” response in the detection task represents conscious perception of the visual stimulus, meaning that the intensity of the internal representation of the stimulus exceeds the subjective threshold. During such an experiment, the intensity of the internal representation of the stimulus may not exceed the subjective threshold, and as a result, participants may not be able to detect the presence of the stimulus (miss trials). In these situations, if participants were able to discriminate an attribute of the stimulus through the objective m-AFC task, then we would assert that the intensity of the internal representation of the stimulus fell between objective and subjective

threshold. Therefore, participants would perceive the stimulus in a non-conscious manner in the zone that is defined between the objective and subjective thresholds. In this situation, participants' overall performance in the m-AFC task is contrasted against chance level in the miss trials. Therefore, by contrasting participants' performance between the detection and m-AFC tasks, we can dissociate conscious from non-conscious perceptions (for other dissociation methods, see Bar & Biederman, 1998; Blake & Fox, 1974)

Regardless of the method that we use to evaluate non-conscious perception, an important assumption is that participants cannot consciously perceive the visual stimuli. This assumption is important: if participants are not completely unaware of visual target, we cannot make a firm conclusion regarding either the dissociation between conscious and non-conscious perception or the dissociation between the neural basis of conscious and non-conscious perception. This dilemma is a potential problem in the studies that use accuracy-based measures to evaluate the dissociation between conscious and non-conscious perception based on the formulation proposed by Cheesman and Merikle (Heeks & Azzopardi, 2015).

According to signal detection theory (SDT; Green & Swets, 1989; Macmillan & Creelman, 2004), in addition to the fundamental differences between conscious and non-conscious perception, there is a risk that confounding variables influence the observed dissociation between these two modes of perception. One of these confounding factors is the interaction of participants' decision criterion (response bias) with their ability to detect visual target (signal) and to discriminate it from irrelevant signals (noise; Cowey, 2010). For every perceptual task (or any other cognitive task that requires classification, such as memory recognition), participants use a decision rule to respond to the demands of the task in a certain way (Macmillan & Creelman, 2004; McNicol, 2005). For example, imagine that we ask a participant to categorize a number of stimuli

into two categories (category A and category B) in which the boundary between the two categories is ambiguous. In this situation, the participant uses a decision rule (cut-off point) to categorize the stimuli. The stimuli below the cut-off point will be categorized as category A and stimuli above the cut-off point as category B. The participant may change his or her cut-off point and this change in the decision rule would result in completely different categorizations of the stimuli than before. We call this decision rule the decision criterion. The decision criterion is function of different factors other than perceptual processes, such as metacognition, and it may be the result of the neural activities in areas beyond the sensory cortices (see Ashby & Soto, 2016 for a review on the neural basis of decision criterion).

In line with this, if we ask participants to judge the presence/absence of a target stimulus with a near threshold intensity (e.g. low contrast) in a series of trials with and without the target, participants may choose different decision rules to respond to demands of this task. They may choose a liberal decision criterion to detect as many targets as possible, and by doing so, they increase the false alarm rate. Participants may also adopt a conservative criterion to avoid false alarms. In this situation, they increase the miss rate. Therefore, adopting a conservative, liberal or optimal decision criterion have different impacts on the observed classification behavior.

In subjective-detection tasks, participants tend to adopt a conservative criterion. That is, in a noisy and uncertain environment, observers adopt a high subjective criterion to avoid false alarms, but by doing so, they ignore some signs of visual target and increase the number of misses. Whereas observers' performance in the m-AFC task may also be prone to the use of conservative criterion, this task is less susceptible to the adoption of a conservative criterion (Cowey, 2010).

This problem is important to consider while investigating the dissociation between conscious and non-conscious perception, and it may also explain some of the controversial

evidence in the literature (such as the association between neural activities in V1 and conscious perception). Therefore, it is crucial to control participants' criterion in both subjective and objective tasks. Moreover, using a bias-free measure to evaluate participants' conscious and non-conscious perception is also crucial because current measures (accuracy-based measures) are not able to separate different factors related to the aforementioned dissociation.

SDT (Green & Swets, 1989; Macmillan & Creelman, 2004) provides us with an appropriate tool to control participants' response bias and measure their ability to discriminate signal from noise: d' , which takes into account both hit rate and false alarm rate, is the index for the ability of participants to discriminate signal from noise. If an experimental condition has a detrimental effect on conscious detection but not on the non-conscious tasks, the ability of participants to discriminate signal from noise (measured by d') for the subjective detection task should be significantly lower than their ability in the objective m-AFC task.

Some studies have utilized the signal-detection method to evaluate the dissociation between conscious and non-conscious perception. For example, Azzopardi and Cowey (1997) showed that a blindsight patient, GY, has a higher sensitivity in 2AFC task compared to his sensitivity in the detection task; this example implies that the lesion to area V1 detrimentally impacted GY's ability to consciously perceive the stimulus, but his non-conscious ability remained intact or was not impacted significantly. Lloyd, Abrahamyan, and Harris (2013) on the other hand, did not find significant difference between subjective and objective sensitivity of participants when they received transcranial magnetic stimulation (TMS) on their V1 100 ms after stimulus onset (the condition called TMS-induced blindsight). Based on Lloyd et al. (2013), non-conscious perception of a visual stimulus within a scotoma, induced by a TMS pulse, is the matter of a

conservative criterion, indicating that TMS pulses on V1 100 ms after stimulus onset impairs conscious and non-conscious perception similarly.

One of the major methods used to dissociate conscious and non-conscious perception is known as continuous flash suppression (CFS; Tsuchiya & Koch, 2005). In CFS, the conscious perception of a constant visual stimulus (target), presented to the non-dominant eye, is masked by the presentation of a series of high contrast, contour-rich masks with different patterns of color and shape (Mondrians) to the dominant eye. Whereas the masks suppress conscious perception of the target, the visual system can still process the target via the non-conscious network, and the suppressed target can influence visual behavior and perceptual decisions in a non-conscious manner.

Non-conscious perception of different visual categories including face recognition (Jiang, Costello, & He, 2007; Stein, Hebart, & Sterzer, 2011; Stein, Senju, Peelen, & Sterzer, 2011), facial-expression recognition (Adams, Gray, Garner, & Graf, 2010; Almeida, Pajtas, Mahon, Nakayama, & Caramazza, 2013; Anderson, Siegel, White, & Barrett, 2012; Stein & Sterzer, 2012; Yang, Zald, & Blake, 2007), and the recognition of objects classified as tools (Almeida, Mahon, & Caramazza, 2010; Almeida, Mahon, Nakayama, & Caramazza, 2008) have been reported with CFS (for review, see Yang, Brascamp, Kang, & Blake, 2014). In addition, some researchers have tried to identify the neural correlates of conscious and non-conscious perception with the CFS method (Jiang & He, 2006; Sterzer, Jalkanen, & Rees, 2009; Watanabe et al., 2011; Yuval-Greenberg & Heeger, 2013; for reviews, see Hesselmann, 2013; Sterzer, Stein, Ludwig, Rothkirch, & Hesselmann, 2014).

Although CFS has been a promising method in examining conscious and non-conscious perception, the issue of subjective criterion compared to objective criterion is an important issue

that we need to consider (Hesselmann, 2013; Sterzer et al., 2014; Yang et al., 2014). That is, because of continual presence of noise (masks) in the visual field, it is possible that participants adopt a conservative criterion in the conscious detection task and ignore any sign of signal (Yang et al., 2014). Participants, on the other hand, may adopt more optimal criterion in the non-conscious tasks. Accordingly, the dissociation between conscious and non-conscious perception with CFS might be due to different criterion setting strategies in conscious and non-conscious tasks, and using bias-free measures is important to investigate this dissociation.

One of the visual categories of interest to researchers is facial expression. Non-conscious perception of facial expression using CFS and other methods has been the topic of extensive investigation in recent years (Adams et al., 2010; Almeida et al., 2013; Anderson et al., 2012; Stein & Sterzer, 2012; Yang et al., 2007). Different studies have provided evidence for non-conscious perception of facial expression in the absence of awareness, and CFS studies (along with studies using other methods) highlighted a visual pathway that bypasses visual cortex, from the superior colliculus (SC) to the posterior nuclei of thalamus and from there to the amygdala, as the neural correlate of non-conscious perception of facial expression (Jiang & He, 2006; Pasley, Mayes, & Schultz, 2004; Williams, Morris, McGlone, Abbott, & Mattingley, 2004; for review, see Diano, Celeghin, Bagnis, & Tamietto, 2017).

Because no study has evaluated the dissociation between conscious and non-conscious perception of facial expression under CFS using bias-free measures, using signal detection methods is crucial to investigate this dissociation. Therefore, the aim of the current study is to explore the possibility that a conservative response criterion for facial expression perception during CFS is responsible for the differences between conscious and non-conscious perception. We hypothesized that the non-conscious perception of facial expressions in absence of visual

awareness under CFS represents a difference between conscious and non-conscious perception. That is, CFS may have a detrimental impact on the sensitivity of participants to detect face stimuli consciously however, their sensitivity to discriminate emotion of face stimuli (through 2AFC task) may be significantly higher than participants' sensitivity for the detection task. Therefore, we predict that, under influence of CFS, participants will have a higher sensitivity in the non-conscious 2AFC task in comparison to the conscious detection task. We stated this hypothesis based on the assumption that, when we present a near-threshold stimulus, participants will show similar detection and 2AFC sensitivity (for example, see Azzopardi & Cowey, 1997). We also predicted that there will be no significant difference between subjective and objective criterion.

We conducted two experiments to tests these predictions. We rendered emotional faces stimuli (fearful vs. neutral) invisible for 500 milliseconds (ms) (Experiment 1) and 700 ms (Experiment 2), and asked participants to judge the presence/absence of the faces with a yes/no detection task and the emotion of faces with the 2AFC task, and to rate their confidence on each of these two tasks.

Experiment 1

The aim of Experiment 1 was to evaluate the sensitivity and the criterion of each participant by using a detection task and a 2AFC task for facial expression perception while employing CFS.

Methods

Participants

Sixteen right-handed participants participated in this experiment (11 females, ages 18-24). We recruited the participants from a pool of psychology undergraduate students through Florida

International University's (FIU) Psychology Research Participants System (SONA) for one credit/hour compensation. All of the participants had normal or corrected-to-normal (with contact lenses) vision. We did not recruit participants with corrected-to-normal vision using eyeglasses, because of the limitations in our setup. The Institutional Review Board of Florida International University approved this study and written informed consent was obtained from all participants.

Stimuli

We used a total of 1000 Mondrians. Mondrians are high contrast, contour-rich images with different patterns of color and shape –named after the artist, Piet Mondrian, because of their resemblance to his work. We used Mondrians with white, black, and gray filled ovals (200×200 pixels) taken (with permission) from the study of Izatt, Dubois, Faivre, and Koch (2014). We chose these Mondrians to keep the masks as similar to the targets as possible and to increase the possibility of suppression (Yang et al., 2014).

The targets consisted of emotional faces (neutral and fearful faces, presented in gray scale) of four different identities (two male and two female), extracted from “California Facial Expressions (CAFE) Database” (Dailey, Cottrell, & Reilly, 2001). To adjust the contrast of the target stimuli, we used GNU Image Manipulation Program (GIMP) version 2.8.18. We reduced the contrast by 40 degrees, but we kept the images' original brightness. Because the original CAFE images are bigger than the masks, we used GIMP to adjust the size of the target stimuli, so that the masks and the targets would be the same size (200×200 pixels). We also presented the faces inside a gray oval to eliminate other facial and bodily parts (like hair and ears) from the image (see Figure 2).

Apparatus

We controlled the stimuli using PsychoPy version v1.82.01 (Peirce, 2007) and presented them with an iMAC pro and DELL E773c CRT monitor (17 inch, 1024 × 768 resolution, 60Hz refresh rate). Participants viewed the CRT monitor from a distance of about 52 cm using a set of prism goggles. The goggles are able to induce two separate visual fields: one for each eye. This induces a visual illusion such that the two images (mask and face) appear in the same physical location in the visual field. We also used a screen divider (to ensure that each eye received information only from its own visual field) and a chin rest (to limit participants' head movements).

Procedure

Each trial started with the binocular presentation of a red fixation point inside a box for 500 ms. Then, 11 masks were presented to the participants' right eye (100 ms each for a total of 1100 ms). The target was presented to the left eye at the same time as the fifth mask and remained on the screen for 500 ms (Figure 2). In one-third of the trials, we did not present any target stimuli, meaning that only the masks were presented on the screen (catch trials). At the end of each trial, participants answered four questions. The first question asked if participants saw the visual stimulus (detection task), and they responded with "yes" or "no." Then, they were asked to rate the confidence of their yes/no responses with the following alternatives: "very confident", "somewhat confident", "a little confident", and "not at all confident." The third question asked participants to guess the emotion of the faces (2AFC question) as either "fearful" or "neutral." They were instructed to guess the answer to this question if they did not think they saw the visual target. Finally, they were asked to rate the confidence of their answer to the 2AFC question.

Each participant completed a single one-hour session during which they completed two blocks of training trials (eight trials each). After the training trials, participants started the experimental trials (4 blocks and 96 trials in each block). They completed as many trials as they could during the remaining time.

Fig. 2 Schematic representation of one trial in Experiment 1.

Analysis

To analyze the acquired data, we used RStudio version 3.3.2. We also used the packages: ez version 4.4-0 (Lawrence, 2012) and pROC version 1.10.0 (Robin et al., 2011).

Non-conscious perception using accuracy-based measure

After calculating rates of hits, misses, false alarms, and correct rejections for both detection and 2AFC tasks, we compared participants' performance in the 2AFC task in the trials that they could

not detect the target (miss trials), against the chance level ($p(c)=0.5$) using one-sample t-tests (two tailed).

Signal detection analysis of detection and 2AFC performance

We calculated perceptual sensitivity (d') (Equation 1) and decision criterion (Equation 2) for both detection and 2AFC tasks. For 2AFC responses we recategorized the trials with a fearful face as target-present trials and the trials with a neutral face as catch (target-absent) trials. Because ten participants had false alarm rates or hit rates of zero in the detection task, we adjusted their responses by adding 0.5 score to all their four response categories to avoid infinite d' score (Macmillan & Creelman, 2004). One participant had negative d' score in the detection task because of an uneven number of trials with and without the target. We, however, did not change this number and did not remove the participant from the analysis (Macmillan & Creelman, 2004).

$$(1) d' = Z(HitRate) - Z(FalseAlarmRate)$$

$$(2) c = \frac{-1}{2} [Z(HitRate) + Z(FalseAlarmRate)]$$

After calculating perceptual sensitivity and decision criterion for detection and 2AFC task, we contrasted the sensitivity of participants in both detection and 2AFC tasks against chance level ($d' = 0$) using two separate one-sample t-tests (two tailed) and evaluated the impact of type of task (detection vs. 2AFC) on perceptual sensitivity and decision criterion, using two separate repeated measure ANOVAs.

Receiver Operating Characteristic Curves

To gain a better understanding regarding the interaction of sensitivity and criterion with type of task, we used participants' confidence ratings for each task to construct two receiver operating

characteristic (ROC) curves (Macmillan & Creelman, 2004; Mickes, Flowe, & Wixted, 2012). In order to do so, we reconstructed detection and 2AFC responses based on confidence rating to each response. For 2AFC responses, we recategorized the responses in a way that the trials with the fearful faces represented the target-present trials and the trials with the neutral faces represented the target-absent trials. Then we constructed two ROC curves for two tasks using pROC package version 1.10.0 (Robin et al., 2011).

The measure of interest in ROC curve analysis was the Area Under the Curve (AUC) of ROC curves for detection and 2AFC responses. We compared AUC of two ROC curves for each participant using the method of DeLong (DeLong, DeLong, & Clarke-Pearson, 1988). Finally, we used paired sample t-test to compare AUCs of ROC curves across all participants.

Results

As depicted in figure 3 (Experiment 1), Participants could discriminate the emotion of the faces in the miss trials at above chance level ($M=0.57$, $SD=0.05$, $95\% CI= 0.54 - 0.60$, $t(15)= 5.41$, $p\leq.001$). Comparing sensitivity of two tasks against chance level ($d' = 0$) showed that participants had higher sensitivity than chance level in both the detection ($M=0.29$, $SD=0.43$, $95\% CI= 0.066 - 0.52$, $t(15)= 2.75$, $p=0.014$) and the 2AFC tasks ($M=0.47$, $SD=0.33$, $95\% CI= 0.29 - 0.64$, $t(15)= 5.72$, $p\leq.001$).

Evaluating the impact of type of task on the sensitivity (Figure 4) suggested that perceptual sensitivity was significantly lower in the detection ($M=0.29$, $SD=.43$) as compared to the 2AFC task ($M=0.47$, $SD=0.33$): $F(15,1)=6.09$, $p=0.026$. In addition, we found a higher level of criterion for the detection task ($M=1.87$, $SD=0.62$) in comparison to the 2AFC task ($M=0.31$, $SD=0.46$), $F(15,1)= 38.28$, $p\leq.001$ (Figure 4). Therefore, participants showed signs of non-conscious

discrimination of fearful from neutral faces, even though they had higher detection criterion than 2AFC criterion.

Fig. 3 Participants' ability to discriminate (2AFC) the facial expression in the miss trials. The left bar (purple bar) represents 2AFC performance in the Experiment 1 and the right bar (green bar) represents 2AFC performance in the Experiment 2.

Fig. 4 The top graph shows participants ability to discriminate signal from noise (sensitivity) in 2AFC and detection tasks and the bottom graph shows the criterion levels for 2AFC and detection tasks.

Comparing the AUCs of ROC curves for both tasks showed that, in 12 out of 16 participants, there was no significant difference between the sensitivity (measured by AUC) of the two tasks (see Table 1 and Figure 5 [S4 and S11]). In 4 participants, however, our analysis showed that participants had higher sensitivity in the 2AFC task than the detection task. Comparing the AUCs of ROC curves across all participants suggests that the 2AFC sensitivity ($M=0.59$, $SD=0.08$) was significantly higher than detection sensitivity ($M=0.54$, $SD=0.07$), $t(15)=4.67$, $p=.0003$. ROC curve analysis showed that participants had residual visual ability in absence of conscious perception and therefore, supported the results from sensitivity analysis in the previous section.

Fig. 5 Example ROC curves for two participants (S4 and S11) from Experiment 1 and two participants (S1 and S7) from Experiment 2. The red curves represent ROC curve for the detection task and the blue curves represent ROC curve for the 2AFC task.

Table 1. ROC curve Analysis of detection and 2AFC performance in experiment 1

Participants	Detection AUC	2AFC AUC	D	P-value (D)
S1	0.5	0.59	3.04	0.003
S2	0.54	0.55	0.34	0.73
S3	0.60	0.56	-0.88	0.38
S4	0.50	0.54	1.07	0.29
S5	0.50	0.52	0.66	0.51
S6	0.53	0.55	0.55	0.58
S7	0.50	0.53	0.55	0.58
S8	0.50	0.57	2.02	0.045
S9	0.51	0.57	1.73	0.085
S10	0.60	0.66	0.91	0.36
S11	0.72	0.84	2.22	0.027
S12	0.53	0.58	1.38	0.17
S13	0.52	0.56	1.09	0.28
S14	0.49	0.57	2.55	0.011
S15	0.49	0.55	1.72	0.87
S16	0.66	0.67	0.19	0.86

Experiment 2

The presentation duration of a face stimulus may impact conscious and non-conscious perception of the face stimulus with CFS (e.g. Barbot & Kouider, 2012). Therefore, the aim of Experiment 2 was to evaluate sensitivity and criterion of participants in a detection and a 2AFC tasks for facial

expression perception while rendering target faces invisible by CFS for a longer time than Experiment 1.

Methods

Participants

Thirteen healthy and right-handed participants participated in this experiment (8 females, ages 18-41). We recruited the participants from a pool of psychology undergraduate students through the FIU SONA system for one credit/hour compensation. Our recruitment criteria was identical to that of Experiment 1. The Institutional Review Board of Florida International University approved this study and written informed consent was obtained from all participants.

Materials and procedure

This experiment was similar to Experiment 1 with two differences. First, the target stimulus was presented for 700 ms. Second, we used 13 masks (100 ms each for a total of 1300 ms) in each trial to adjust the design to the new target presentation time. Like Experiment 1, we presented the target at the same time with the fifth mask, but it remained on the screen for 700 ms. With these changes, we kept other conditions (such as the number of masks that were presented before and after target presentation) similar to the first experiment.

Analysis

Similar to Experiment 1, after calculating four categories of responses for both detection and 2AFC tasks, we compare participants' performance in the 2AFC task in the miss trials, against the chance level ($p(c)=0.5$) using one-sample t-test (two tailed).

Then we calculated perceptual sensitivity (d') and decision criterion for both detection and 2AFC tasks. For 2AFC responses we recategorized the trials with a fearful face as target-present trials and the trials with a neutral face as catch (target-absent) trials. Four participants had zero hits and zero false alarms in the detection task. Similar to Experiment 1, we adjusted their responses by adding 0.5 score to all of their four response categories (Macmillan & Creelman, 2004). Two participants had negative d' score in the detection task because of uneven number of trials with and without target. We did not change these numbers and did not remove the participants from the analysis (Macmillan & Creelman, 2004). Finally, we used participants' confidence ratings for each task to construct two ROC curves.

Results

One sample t-test on 2AFC performance (Figure 3- Experiment 2) showed that participants could discriminate the emotion of the faces in the miss trials at above chance level ($M=0.57$, $SD=.05$, $95\% CI= 0.54 - 0.59$, $t(12): 5.18$, $p\leq.001$). Comparing sensitivity of two tasks against chance level ($d' = 0$) showed that participants had higher sensitivity than chance level in both detection ($M=0.71$, $SD=0.84$, $95\% CI= 0.20 - 1.21$, $t(12)= 3.03$, $p=0.01$) and 2AFC task ($M=0.65$, $SD=0.54$, $95\% CI= 0.32 - 0.98$, $t(12)= 4.33$, $p=0.0009$).

Evaluating the impact of type of task on the sensitivity (Figure 6) showed that the perceptual sensitivity was not different between detection ($M=0.71$, $SD=0.84$) and 2AFC ($M=0.65$, $SD=0.54$) tasks, $F(12,1)=0.204$, $p=0.66$, although participants showed higher criterion in the detection task ($M=1.28$, $SD=0.76$) compared to the 2AFC task ($M=0.56$, $SD<0.65$), $F(12,1)=5.31$, $p<.001$ (Figure 6).

Fig. 6 The top graph shows participants ability to discriminate signal from noise (sensitivity) in 2AFC and detection tasks and the bottom graph shows the criterion levels for 2AFC and detection tasks.

Comparing AUCs of ROC curves for both tasks suggested that, in 10 out of 13 participants, there were no significant differences between the sensitivities (measured by AUC) of the two tasks (See Table 2 and Figure 5 [S1 and S7]). In 3 participants, however, our analysis showed that 2AFC task had higher sensitivity than detection. Comparing AUCs of ROC curves across all participants indicated that there was no significant difference between detection ($M=0.58$, $SD=0.09$) and 2AFC sensitivity ($M=0.60$, $SD=0.11$), $t(12)= 1.72$, $p=0.11$. ROC curve analysis supported the results from sensitivity analysis in the previous section and did not provide evidence for residual visual responses in absence of visual awareness

Table 2. *ROC curve Analysis of detection and 2AFC performance in experiment 2*

Participants	Detection AUC	2AFC AUC	D	P-value(D)
S1	0.75	0.87	2.84	0.005
S2	0.54	0.67	2.48	0.014
S3	0.71	0.69	-0.46	0.65
S4	0.50	0.52	0.75	0.45
S5	0.67	0.77	3.22	0.001
S6	0.64	0.59	-1.69	0.091
S7	0.50	0.53	0.85	0.40
S8	0.50	0.49	-0.13	0.90
S9	0.54	0.54	0.095	0.92
S10	0.54	0.53	-0.093	0.93
S11	0.52	0.54	0.36	0.72
S12	0.56	0.53	-0.59	0.56
S13	0.53	0.57	0.81	0.42

Discussion

We were interested in using CFS to evaluate conscious and non-conscious perception of facial expressions (fearful vs. neutral). In our studies, we rendered face stimuli invisible for 500 ms (Experiment 1) and 700 ms (Experiment 2) and then evaluated participants' conscious and non-conscious perception using bias-free measures extracted from SDT. We hypothesized that the non-conscious perception of facial expression in the absence of visual awareness with CFS represents a difference in underlying processes between conscious and non-conscious perception. That is,

when we render emotional faces invisible with CFS, participants will have higher sensitivity in the non-conscious 2AFC task in comparison to the conscious detection task. Our results supported this hypothesis when we rendered the face stimuli invisible for 500 ms but not when we did so for 700 ms. That is, participants showed higher sensitivities in the 2AFC than detection task when we presented the target stimulus for 500 ms. On the other hand, when we presented the target stimulus for 700 ms, participants showed similar sensitivity level for both detection and 2AFC tasks.

Our results indicate that participants showed residual ability to discriminate signal (fearful face) from noise (neutral face) only when we rendered the face stimuli invisible for 500 ms. That is, in this condition, the non-conscious perception represents dissociation processes related to conscious and non-conscious perception. Therefore, the observed non-conscious processing of facial expression while we rendered the face target invisible for 500 ms with CFS, was due to the dissociation processes.

On the other hand, our results indicate that participants' ability to discriminate signal from noise is deteriorated similarly for both detection and 2AFC tasks while rendering the face stimuli invisible for 700 ms. That is, the non-conscious ability of participants to discriminate facial expressions while we suppress the conscious perception of face stimuli with CFS, for 700 ms, is due to adopting a conservative criterion in the detection task rather than dissociation processes. Therefore, participants might be able to detect face stimuli consciously, but, because of continual presence of noise they adopted a conservative criterion to avoid false alarms.

Whereas sensitivity and group ROC curve analyses are aligned with each other, individual ROC curve analysis did not provide full support of those two analyses. Even though some participants showed signs of residual non-conscious perception, other participants did not. This might be due to the relatively high variability in sensitivity across participants. As some studies

have shown, conscious and non-conscious perception under influence of CFS varies among different participants (e.g. Almeida et al., 2013; Bahrami et al., 2010; Jiang et al., 2007; also see Yang et al., 2014). That is, the magnitude of the impact of CFS on conscious and non-conscious perception varies from participant to participant. Our results also showed high variance among the participants (see figure 7). This might be the reason of the discrepancy between group and individual ROC analysis results.

Fig. 7 Dot Plot depicting the distribution of individual sensitivity measures in Experiment 1 (left graph) and Experiment 2 (right graph)

According to our results, the non-conscious perception of facial expression with CFS might be time dependent (also see Barbot & Kouider, 2012), even though CFS has the ability to suppress target stimuli from awareness for several seconds (Tsuchiya & Koch, 2005). Therefore, it is

important to note that our results only apply to situations in which face stimuli are rendered invisible for 500 and 700 ms and also for situations in which participants should discriminate fearful from neutral faces. Therefore, we will need to evaluate this dissociation for other suppression durations and for other categories of visual stimuli as well.

This study provided additional support for the importance of using bias-free measures for evaluating the dissociation between conscious and non-conscious perception. Using bias-free measures is critical for scientific study of conscious perception because without such methods, it would be impossible to make conclusions regarding the dissociation between conscious and non-conscious perception. That is, we would fail to dissociate conscious and non-conscious perception and evaluate the neural basis of each of these two modes of perception. Therefore, we might observe certain neural activities in the absence of conscious perception and highlight them as the neural substrates of non-conscious perception. In the absence of bias-free measures, however, we cannot conclude that these activities are happening in the absence of conscious perception. Although these activities might be due to the perceptual processes outside conscious awareness, we might observe them only because participants adopt a conservative criterion, thereby ignoring the evidence for the presence of the target.

This leads to a major issue in the science of consciousness: how to measure conscious perception? Whereas the past couple of decades have witnessed a tremendous progress in this field, this question remains problematic. Although yes/no detection task has provided us with valuable information, it cannot provide us with an unbiased and objective assessment of conscious perception. Using yes/no detection tasks, participants may choose a liberal or a conservative criterion and thus overestimate or underestimate the potential of their conscious perception. This

may be misleading for determining the underlying process differences between conscious and non-conscious perception.

One way to address this problem is to use SDT bias-free measures to assess and dissociate both sensory and decision processes. As our results showed, applying SDT bias-free measures showed that adopting a conservative criterion might be the reason for the observed dissociation between conscious and non-conscious perception of facial expression while employing CFS. Some other studies have also evaluated conscious and non-conscious perception with this method. For example, Azzopardi and Cowey (1997) showed that blindsight patient GY has lower sensitivity in a detection than 2AFC task (also see Azzopardi & Cowey, 1998), and Yoshida and Isa (2015) found similar results regarding the ability of two Japanese Macaque monkeys with lesion to their V1 to discriminate location of the target stimulus via the saccadic eye movement. Lloyd et al, (2013), however, showed the non-conscious responses in TMS-induced blindsight is the function of a conservative criterion by the participants. Other researchers have shown that there is no significant difference between sensitivity of participants in conscious and non-conscious tasks while using backward masking (Balsdon & Azzopardi, 2015; Heeks & Azzopardi, 2015).

Therefore, when we aim to study the dissociation between conscious and non-conscious perception, SDT provides us with powerful tools to evaluate this dissociation. We can also use these tools to evaluate the neuro-computational mechanisms of these two modes of perception.

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