Neuroscience

tCFS: A new 'CFS tracking' paradigm reveals uniform suppression depth regardless of target complexity or salience

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Abstract

When the eyes view separate and incompatible images, the brain suppresses one image and promotes the other into visual awareness. Periods of interocular suppression can be prolonged during continuous flash suppression (CFS) - when one eye views a static 'target' while the other views a complex dynamic stimulus. Measuring the time needed for a suppressed image to break CFS (bCFS) has been widely used to investigate unconscious processing, and the results have generated controversy regarding the scope of visual processing without awareness. Here, we address this controversy with a new 'CFS tracking' paradigm (tCFS) in which the suppressed monocular target steadily increases in contrast until breaking into awareness (as in bCFS) after which it decreases until it again disappears (reCFS), with this cycle continuing for many reversals. Unlike bCFS, tCFS provides a measure of suppression depth by quantifying the difference between breakthrough and suppression thresholds. tCFS confirms that: (i) breakthrough thresholds indeed differ across target types (e.g., faces vs gratings, as bCFS has shown) – but (ii) suppression depth does not vary across target types. Once the breakthrough contrast is reached for a given stimulus, all stimuli require a strikingly uniform reduction in contrast to reach the corresponding suppression threshold. This uniform suppression depth points to a single mechanism of CFS suppression, one that likely occurs early in visual processing because suppression depth was not modulated by target salience or complexity. More fundamentally, it shows that variations in bCFS thresholds alone are insufficient for inferring whether the barrier to achieving awareness exerted by interocular suppression is weaker for some categories of visual stimuli compared to others.

Significance statement

Research on unconscious vision has proliferated recently, often employing the continuous flash suppression (CFS) method in which rapidly changing shapes viewed by one eye suppress the other eye's image from awareness. If that suppressed image is progressively strengthened in contrast it will eventually break suppression and emerge into visible awareness. Low breakthrough thresholds are claimed to indicate unconscious processing during suppression. We introduce a method that quantifies breakthrough thresholds and suppression thresholds, thus providing a lower bound missing from previous CFS research.

Comparing various image types, including those claimed to undergo unconscious processing, all images show equal suppression when both thresholds are measured. We thus find no evidence of differential unconscious processing and conclude reliance on breakthrough thresholds is misleading without considering suppression thresholds and leads to spurious claims about unconscious processing.

eLife assessment

This **valuable** study introduces an innovative method for measuring interocular suppression depth, which implicates mechanisms underlying subconscious visual processing. The evidence is **solid** in suggesting a limitation of measuring conventional bCFS threshold alone that could be remediated by the new method. It will be of interest not only to cognitive psychologists and neuroscientists who study sensation and perception but also to philosophers who work on theories of consciousness.

Introduction

The quest to understand visual processing outside of awareness is tantalising but notoriously challenging to implement (Breitmeyer, 2015; Hesselmann & Moors, 2015; Holender, 1986; Logothetis, 1998; Newell & Shanks, 2014; Schmidt, 2015). There are controversial claims of higher-level semantic processing (Lanfranco et al., 2022; Mudrik et al., 2014; Stein & Sterzer, 2014; Sterzer et al., 2014), object categorization (Kouider & Dehaene, 2007; Rees, 2007; Sterzer et al., 2014), and abstract reasoning (Hassin, 2013; Sklar et al., 2012) occurring outside of awareness. A number of methods exist for manipulating visual awareness (Kim & Blake, 2005), with two of the most popular in recent years being binocular rivalry (Alais & Blake, 2014) and continuous flash suppression (CFS: (Fang & He, 2005; Tsuchiya & Koch, 2005). Both rely on interocular suppression induced by dissimilar monocular images independently presented to each eye, the result being that only one eye's image is perceived (i.e., dominates) at any given moment, with the other suppressed from awareness. For images approximately matched in salience, as often is the case in binocular rivalry (Alais & Blake, 2014; Wang et al., 2022), monocular suppression lasts for just a few seconds before switching to suppress the other eye (and so on, alternating irregularly over time). With CFS, a highly salient stream of dynamic images seen by one eye suppresses a smaller, weaker target presented to the other for considerably longer periods of suppression that can last tens of seconds. The potency of CFS has great appeal when it comes to assessing residual effectiveness of different categories of visual stimuli blocked from awareness by CFS.

A commonly used variant known as "breaking CFS" (bCFS) was introduced by (Jiang et al., 2007) in which the suppressed target slowly ramps up from low contrast until it becomes sufficiently strong to break suppression and achieve visibility. Time to breakthrough has become a popular measure, and differences in breakthrough times among various image types have been used to support claims for unconscious processing of certain visual images. According to this line of reasoning, image types that consistently emerge from suppression more rapidly than do other image types are construed to be ones that receive prioritized processing outside of awareness. To give three examples of this purported effect, faces portraying emotional expressions break suppression faster than do neutral faces (Alais, 2012; Jiang et al., 2007; Tsuchiya et al., 2009; Yang et al., 2007), complex scenes containing incongruent objects break suppression faster than do congruent scenes (Mudrik et al., 2011), and native words break suppression faster than do unfamiliar foreign words (Jiang et al., 2007). Sceptics argue, however, that differences in breakthrough times can be attributed to low-level factors such as spatial frequency, orientation and contrast that vary between images (Gayet et al., 2014; Moors, 2019; Moors et al., 2016, 2017; Moors & Hesselmann, 2018; Stuit et al., 2023), and more fundamentally, that breakthrough times alone are insufficient to measure differential unconscious processing (Stein, 2019).

Conclusions based on a comparison of bCFS breakthrough times between different image categories suffer from a problem of unidirectionality and a false assumption of image equivalence[1]. Images producing faster breakthrough times (equivalently, lower breakthrough contrasts) are interpreted as undergoing residual processing outside of awareness, adding to their salience and weakening their interocular suppression (Mudrik et al., 2011; Sterzer et al., 2011; G. Zhou et al., 2010; W. Zhou et al., 2010)). An implicit assumption here is that as all images were initially invisible, the depth of interocular suppression was thus weaker for images that break suppression more quickly (i.e., produce faster reaction times, as sometimes stated). Yet, the depth of interocular suppression is rarely measured in CFS paradigms (see Tsuchiya et al,. 2006 for an exception), and to our knowledge, has not been explicitly compared between image categories.

One method for measuring interocular suppression is to compare the threshold for change-detection in a target when it is monocularly suppressed and when it is dominant, an established strategy in binocular rivalry research (Alais, 2012; Alais et al., 2010; Alais & Melcher, 2007; Nguyen et al., 2003). Probe studies using contrast as the dependent variable for thresholds measured during dominance and during suppression can advantageously standardise suppression depth in units of contrast within the same stimulus (e.g., Alais & Melcher, 2007; Ling et al., 2010). Ideally, the change should be a temporally smoothed contrast increment to the rival image being measured (Alais, 2012), a tactic that preludes abrupt onset transients and, moreover, provides a natural complement to the linear contrast ramps that are standard in bCFS research. In this study, we measure bCFS thresholds as the analogue of change-detection during suppression, and as their complement, record thresholds for returns to suppression (reCFS). We do this by including a bidirectional measure in which the target contrast steadily decreases (ramps down) over time, eventually culminating in the target's transition from dominance to suppression. By comparing the thresholds for a target to transition into (reCFS) and out of awareness (bCFS), we recognise that the criterion for change is much higher, and as a result expect larger suppression depths (on average) than those recorded in rivalry research. More importantly, however, by averaging the difference between bCFS and reCFS thresholds, a key analogue of suppression depth that has been missing from the CFS literature can be provided and compared between image categories. **Figure 1** outlines hypothetical results that can be obtained when recording reCFS thresholds as a complement to bCFS thresholds in order to measure suppression depth.

Here, we introduce a novel method termed 'tracking CFS' (tCFS) which combines alternating down-ramped and up-ramped targets, to provide a measure of suppression depth that allows a rigorous test of claims that certain image types undergo less suppression than others (see **Figure 2**). The participant views a visible target as it declines in contrast until it becomes suppressed. When suppression is reported the contrast change reverses direction and the participant indicates when the target emerges out of dominance and is seen once again (triggering a contrast decrease again, and so on over many reversals). By continually tracking thresholds over time for breakthroughs (bCFS) and succumbing (reCFS) to suppression, tCFS is very efficient, makes no assumptions of image equivalence, and provides inherently bidirectional measures of CFS.

To preview the results, across three experiments we find no evidence using the tCFS paradigm for differences in suppression depth among several image categories (i.e., faces, objects, several types of gratings, and visual noise). We do replicate the common observation that breakthrough thresholds differ across image categories, but now we find that reCFS thresholds covaried with bCFS thresholds across all image categories, meaning that suppression depth was constant for

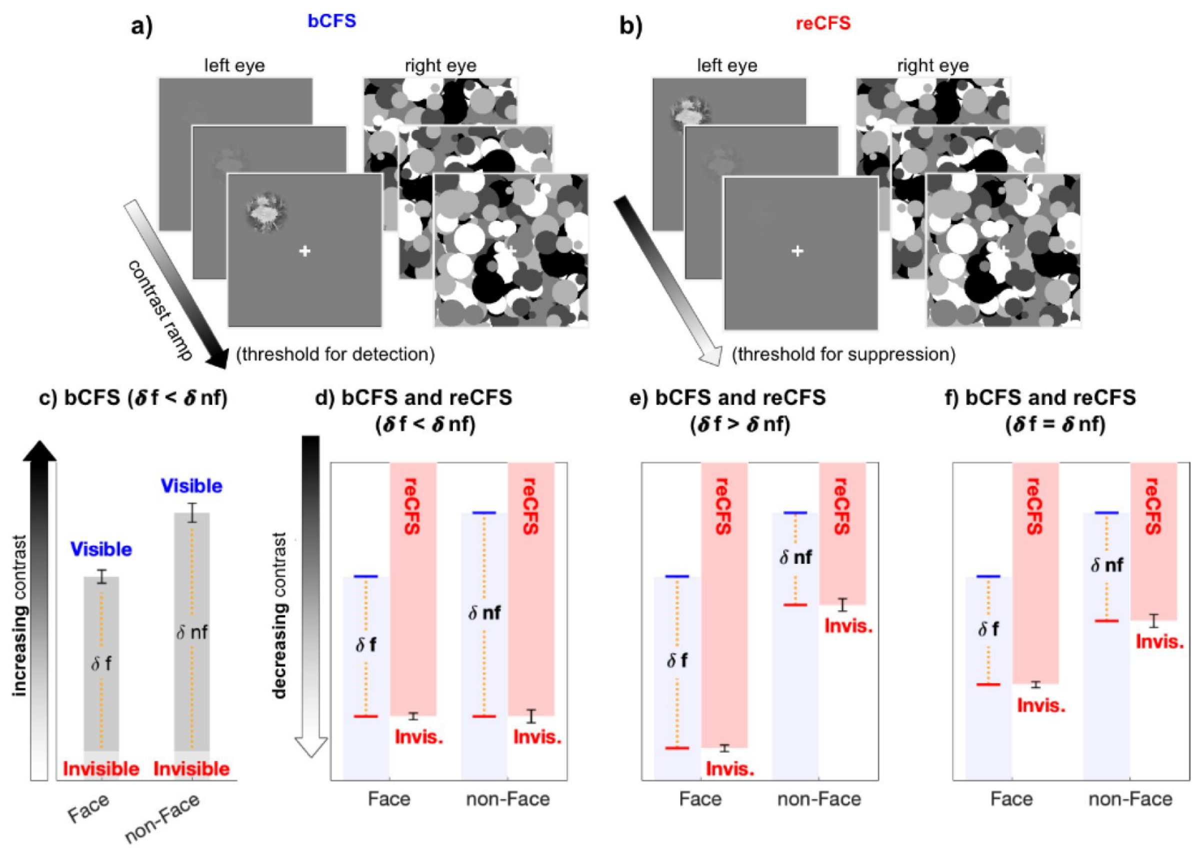


Figure 1.

The critical measure of suppression depth remains untested in CFS. **a,b)** Example stimulus displays for the discrete trials, during which (a) a low-contrast target steadily increases in contrast until visibility is reported (bCFS), and (b) discrete reCFS trials, with a high-contrast target decreasing until target invisibility is reported. **c)** A typical bCFS result, in which a target image (here a face or non face) is initially weak and steadily increases until it breaks suppression. Faster breakthrough times (lower contrast) for face stimuli are often interpreted as evidence that faces undergo expedient processing that counteracts their susceptibility to suppression relative to other visual stimuli. Without also measuring suppression thresholds for each stimulus, this conclusion is premature. **d-f)** To define the magnitude of suppression during CFS, it is necessary to measure the contrast thresholds at which stimuli enter and exit awareness, with the difference indicating suppression depth. Red bars display hypothetical results measuring the contrast at which an initially visible stimulus with decreasing contrast becomes suppressed by the mask (reCFS). The results of panel **c** are reproduced in d-f in light blue. **d)** If the reCFS thresholds for face and non-face images are the same, this would support reduced suppression depth for faces (as LJ face < LJ non-face). **e)** Alternatively, the reCFS thresholds for faces and non-faces might differ, with the face remaining visible at a lower contrast than non-face images (lower reCFS threshold), indicating more suppression for faces than non-faces (as LJ face > LJ non-face). **f)** Finally, the reCFS thresholds might differ between faces and non-faces but by an amount equivalent to their bCFS differences, indicating the same suppression depth for both image types (as LJ face = LJ non-face). Such a result would argue against enhanced unconscious processing of face stimuli.

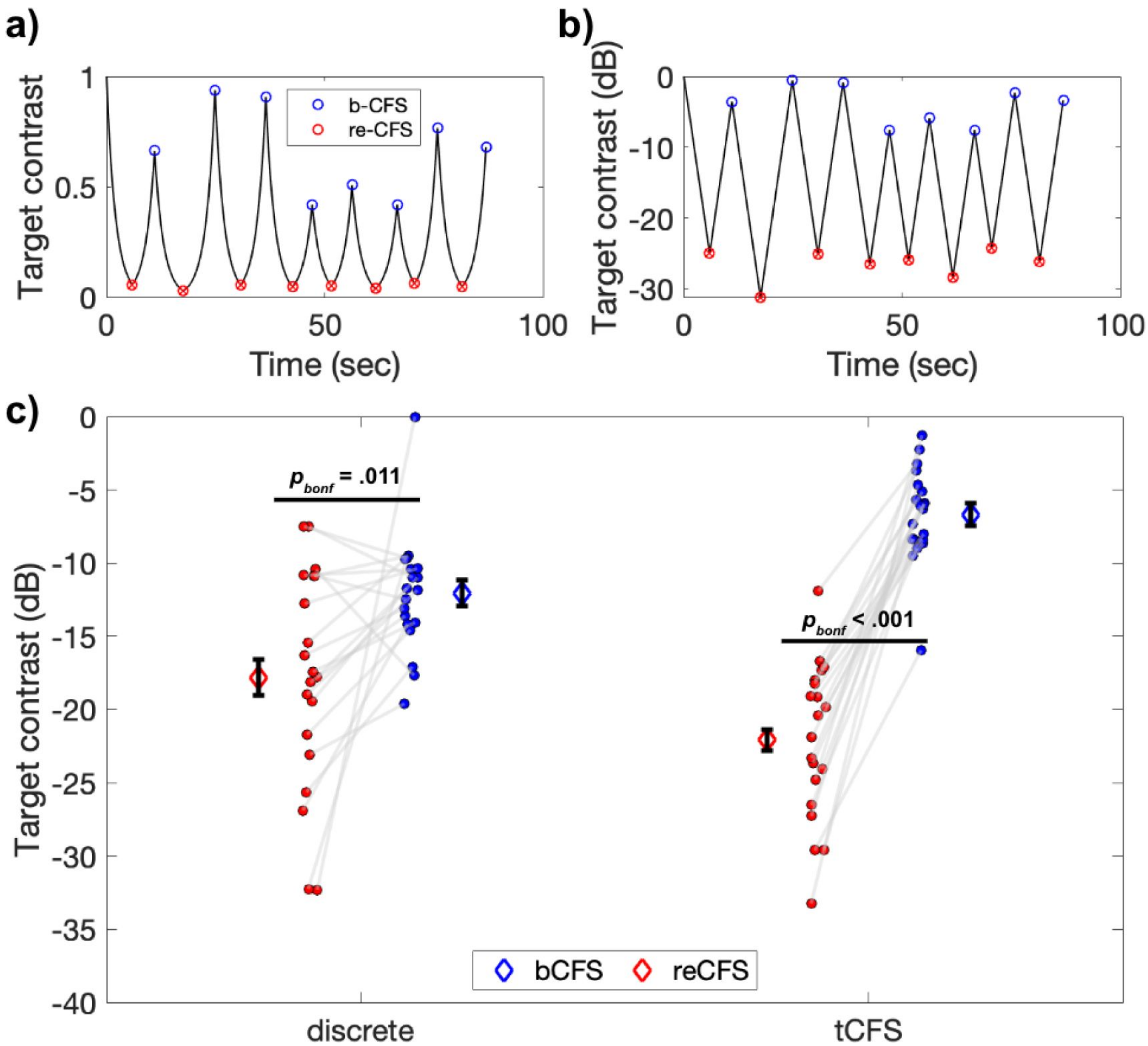


Figure 2.

Example tCFS trial and comparison to discrete conditions. **a-b)** Example tCFS trial from one participant, showing the change in contrast over time. Red markers indicate the level at which a target with decreasing contrast became suppressed (reCFS) and blue markers indicate traditional bCFS responses (breakthrough of contrast-increasing target). The same trial is shown with target contrast in decibel scale in b. Because the human visual system has a logarithmic contrast response, it is appropriate to increase/decrease target contrast logarithmically as in b, to create a contrast change that is perceptually linear. **c)** Interaction between thresholds and condition type. Individual blue and red dots display participant means for bCFS and reCFS respectively. Grey lines link thresholds per participant, per condition. Blue and red diamonds display the mean across participants, and error bars plot ± 1SEM corrected for within participant comparisons (Cousineau, 2005).

faces, objects, gratings and visual noise. In other words, we find no evidence to support differential unconscious processing among these particular, diverse categories of suppressed images.

General Methods

Participants

A total of 36 undergraduate psychology participants volunteered in exchange for course credit. All participated with informed consent and had normal or corrected-to-normal vision. Our sample size for Experiment 1 was based on power estimates to detect a moderate sized effect in a 2 x 2 repeated-measures design (Faul et al., 2009), while also exceeding the typical sample size used in bCFS studies to compensate for our novel paradigm (e.g., n = 10, Cha et al., 2019, n = 10–16, Han et al., 2021). We adjusted our power analysis after observing a strong effect size for the difference between bCFS and reCFS thresholds when using the tCFS method, resulting in fewer participants in Experiments 2 and 3. Experiment 1: N = 20, (15 females), Experiment 2: N = 18 (12 females), Experiment 3, N = 17 (11 females). All participants in Experiment 3 also did Experiment 2, and one author (JC) also completed experiments 2 and 3. This study was approved by the University of Sydney Human Research Ethics Committee (HREC 2021/048).

Apparatus

Visual stimuli were displayed on a Mac Pro (2013; 3.7 GHz Quad-Core Intel Xeon E5) computer, displayed on an Apple LED Cinema monitor (24 inch, 1920 x 1200 pixel resolution, 60 Hz refresh rate), running OS X El Capitan (10.11.6). All experiments were programmed using custom MATLAB code, and displayed using Matlab (ver R2017b) and Psychtoolbox (ver 3.0.13; Brainard et al., 1997). Responses were collected via the left mouse button of the right hand. A mirror stereoscope was used to partition participant's vision into separate left- and right-eye views, located approximately 51 cm from the screen, with a total optical path length of 57 cm.

Stimuli

Participants dichoptically viewed a high-contrast Mondrian mask pattern (400 x 400 pixels, 7° x 7°) with one eye and a small target stimulus (130 x 130 pixels, 2.2° x 2.2°) with the other eye. Two binocularly presented white squares surrounded the mask and served as a fusion lock to maintain stable fusion, and each eye had a central fixation cross (18 x 18 pixels; 0.3° x 0.3°). The Mondrian pattern was greyscale and consisted of overlapping circles of various sizes and intensities and was updated every fifth video frame (12 Hz). The mask's RMS contrast ranged between 0.07 and 0.09. As previous research has indicated that achromatic masks may be optimal to suppress achromatic targets (reviewed in (Pournaghdali & Schwartz, 2020), we opted for grayscale Mondrian patterns to match our targets.

In all experiments targets were viewed by the right eye and were selected at random from a set that was standardised in RMS contrast (20%) and mean luminance (before contrast ramping was applied). Target contrast was ramped up or down by scaling the target image's standard contrast within a range of .02 to 1.0. Importantly, all contrast scaling was done on a logarithmic scale in decibel units (i.e., conDb = 20 x log10(con)) to make the changing contrast effectively linear, thus coinciding with the visual system's logarithmic contrast response function. Minimum (.02) and maximum (1.0) contrast values were thus - 33.98 and 0 dB, respectively, and contrast steps were .07 dB per video frame. In experiment 3, where the rate of target contrast change was manipulated, the contrast steps were .035, .07, or .105 dB units per video frame. Target location varied between trials, drawn from a uniform distribution of 200 x 200 pixels centred on the fixation cross.

Procedure

Participants were given practice trials until they were familiar with CFS and the task used in these experiments. Participants were instructed to respond via mouse click the moment their subjective visibility of the target stimulus changed (either when a visible target became suppressed, or when a suppressed target became visible). Realizing that phenomenological quality of reversals may differ among participants (Moors et al., 2017; Zadbood et al., 2011), we encouraged participants in our study to establish a criteria for target appearance/disappearance in the practice session and to maintain it throughout the experiment. In all experiments, the dependent variable was the target contrast at the moment when a change in target visibility was judged to have occurred (either breaking suppression or succumbing to suppression).

Experiment 1 - Using tCFS to measure suppression depth

Our first experiment tested two different procedures for measuring reCFS and bCFS thresholds: a continuous tracking procedure and a discrete trials procedure similar to that used in previous bCFS research. We hypothesised that a difference between bCFS and reCFS thresholds would provide evidence for a contrast range (i.e., suppression depth) between awareness and suppression, in contrast to the possibility of a given contrast threshold determining a narrow awareness/suppression border. By comparing the results between discrete and continuous methods, we sought to establish the feasibility of collecting multiple thresholds within a single-trial, allowing the rapid quantification of suppression depth in CFS paradigms. Experiment 1 compared CFS thresholds for targets (faces and objects) increasing in contrast and decreasing in contrast (i.e., bCFS and reCFS thresholds) in discrete trials and in continuous tracking trials, in a 2 x 2 repeated-measures, within-subjects design. In the discrete conditions, participants completed eight blocks of eight trials, during which target contrast always changed in one direction - either increasing from low to high as is typically done in bCFS studies to measure breakthrough thresholds, or decreasing from high contrast to low to measure a suppression threshold. In the continuous condition, the target contrast tracked down and up continuously, reversing direction after each participant response. Continuous trials always began with the target decreasing from maximum contrast so that the participant's first response was to report when it disappeared, which caused target contrast to increase until breakthrough was reported, which caused it to decrease again until suppression, etc.. Continuous trials terminated after 16 reports of change in target visibility. When the contrast time series is plotted as shown in **Figure 2b**, the plot shows eight upper turning points where the target broke into awareness (bCFS thresholds) and eight lower turning points where the target became re-suppressed (reCFS thresholds). The order of discrete and continuous blocks was counterbalanced and randomized across participants. Images for the eight trials of each block type were drawn from the same set of four faces and four naturalistic objects, with no repetitions within a block. Before each block began, participants completed a series of practice trials that utilised an independent set of six images. They were able to complete practice trials as many times as they wished until they had confidently established interocular fusion and were comfortable with the requirements of the task.

Experiment 2 - The effect of image category

Experiment 2 tested the suppression depth obtained for different image categories. Experiment 2 used only the continuous tracking 'tCFS' method and compared five image types (faces, familiar objects, linear gratings, phase scrambled images, and polar patterns that were radial lines or concentric circles). The trials contained 20 reports (10 bCFS and 10 reCFS thresholds) and the data were analysed in a 5 (image type) x 2 (bCFS vs reCFS thresholds) within-subjects, repeated-measures ANOVA. There were 10 tracking trials, with each trial containing a single target image from a subset of ten (two of each image category, randomly ordered for each participant).

Experiment 3 - Rate of contrast change on suppression depth

Experiments 1 and 2 introduced the tCFS method and demonstrated a uniformity of suppression depth across multiple target image categories. This uniformity of suppression depth could indicate that neural events mediating CFS suppression are not selective for complexity or semantic meaning, and like popular models of binocular rivalry, could instead be based on low-level reciprocal inhibition and neural adaptation processes (Alais et al., 2010; Kang & Blake, 2010; McDougall, 1901), in which case suppression depth should vary with the rate of contrast change of the monocular target. More specifically, based on the adapting mutual inhibition model, we predicted that at a slower rate of contrast change neural adaptation for the monocular target would increase, lowering the amount of contrast change necessary to transition between visibility states. Similarly, a faster rate of target contrast change would reduce the time for neural adaptation of the monocular target, resulting in an increase in the required change in contrast necessary to transition a target into and out of awareness. Expressed in operational terms, the depth of suppression should increase with the rate of target change, which was the focus of Experiment 3.

Experiment 3 used the tCFS method and compared the rate of target contrast change (slow, medium, fast) across four image categories (faces, objects, linear gratings, and phase scrambled images). The trials contained 20 reports (10 bCFS and 10 reCFS thresholds) and the data were analysed in a 3 (contrast change rate) x 4 (image type) x 2 (bCFS vs reCFS thresholds) repeated-measures, within-subjects design. The medium rate of change was the same as used in Experiments 1 and 2, and the slow and fast rates were 0.5 and 1.5 times the medium rate, respectively. There were 12 tracking trials, given by the factorial combination of four target image types repeated at the three rates of target contrast change (in a randomised order for each participant).

Data Analysis

Data analysis was performed in Matlab (ver R2022a), and SPSS/JASP (ver 28). Initial inspection identified 1 participant for exclusion (from Experiment 3), based on failure to follow task instructions. For visualization and analysis, all contrast thresholds are expressed in decibel units.

We performed Bayesian model comparison to quantify evidence for and against the null in JASP, using Bayesian repeated measures ANOVAs (uninformed prior with equal weight to all models). We report Bayes factors (*B*) for main effects of interest (e.g. effect of image type on suppression depth), as evidence in favour compared to the null model ($BF_{10} = B$). Following the guidelines recommended in (Dienes, 2021), *B* values greater than 3 indicate moderate evidence for H1 over H0, and *B* values less than 1/3 indicate moderate evidence in favour of the null. *B* values residing between 1/3 and 3 are interpreted as weak evidence, or an insensitivity of the data to distinguish between the null and alternative models.

Model Fitting

We additionally quantified the change in relative contrast over time, and evaluated a series of model fits to describe these data. For this analysis, bCFS and reCFS thresholds were first averaged within their respective response number, enabling a comparison of thresholds over the course of each trial. The modelling used the absolute change in contrast between each sequential threshold in the tracking series as its dependent variable, which we modelled after detrending, per participant, and at the group level.

We compared three basic models to this data. All models were fit with a non-linear least-squares approximation using a maximum of 400 iterations (lsqcurvefit.m in MATLAB) The first was a simple cubic polynomial with three free parameters:

$$1)\quad ax^3 + bx^2 + cx$$

where a, b and c are coefficients for the cubic, quadratic and linear term. We also fit a simple harmonic oscillator with three free parameters:

$$2)\quad a \times \sin(b \times t + c)$$

Where a is amplitude, b is frequency, c is a phase offset, and t is time. We also fit a damped harmonic oscillator model with four free parameters:

$$3)\quad a \times e^{(-b \times t) \times \sin(c \times t + d)}$$

Where a and b describe the amplitude and damping coefficient of decay, and c and d describe the frequency and phase shift of the oscillatory response.

To fit each model, we linearly interpolated between the turning points (thresholds) in the tCFS time series of each trial to increase the observations to 1000 samples, and estimated the goodness of each fit through a series of steps. First, we calculated the sum of squared residual errors for each fit (SSE), and calculated the Bayesian Information Criterion (BIC) using equation 4:

$$4)\quad BIC = n \times \log(SSE/n) + k \times \log(n);$$

Where n represents the number of observations in the dataset, SSE is the sum of squared errors, and k is the number of parameters in the model. The BIC allows a comparison of model fits while taking into account the goodness of fit and complexity of each model. It includes a penalty on the number of parameters in the model by including a term that scales with the logarithm of sample size. When comparing two models, the model with a lower BIC is considered favourable, with a change of 0 to 2 BIC as weak evidence in favour, and 6 to 10 as strong evidence in favour (Kass & Raftery, 1995),

Results

Experiment 1

Many previous bCFS studies have shown that *increasing* contrast eventually causes a target image to overcome interocular suppression (i.e., emerge into awareness). To our knowledge, however, none has investigated the contrast at which an initially visible image succumbs to suppression as its contrast is *decreased*. Experiment 1 uses the tCFS method to continuously track changes in target visibility as it rises and falls in contrast. As shown in **Figure 2b**, this provides a series of bCFS thresholds (upper turning points) as well as thresholds for the target's re-suppression (lower turning points: reCFS thresholds). We compare these thresholds to those obtained with a discrete procedure in which contrast either increased steadily from a low starting point until breakthrough (standard bCFS measure) or decreased steadily from a high starting point until suppression was achieved. On each trial the target image was either a face or a familiar object, with the images all matched in size, RMS contrast and mean luminance.

A repeated-measures ANOVA revealed a significant main effect of threshold, such that bCFS thresholds were significantly higher than reCFS thresholds ($F(1,19) = 50.39$, $p < .001$, $\eta_p^2 = .73$). There was also a significant interaction between threshold and condition ($F(1,19) = 41.19$, $p < .001$, $\eta_p^2 = .68$), indicating that the difference between bCFS and reCFS thresholds was influenced by whether they were recorded using the discrete trial procedure or the continuous trial procedure. Subsequent post-hoc tests revealed that bCFS and reCFS thresholds differed within each type of procedure (Discrete: $t(19) = 2.89$, $p = .009$, $d = 0.65$ Continuous: $t(19) = 12.12$, $p < .001$, $d = 2.7$). Overall, the suppression depth (i.e., the difference between bCFS and reCFS thresholds) was larger with the continuous procedure ($M = -15.40$ dB, $SD = 5.68$) compared to the discrete procedure ($M = -5.74$ dB, $SD = 8.89$), $t(19) = 6.42$, $p < .001$, $d = 1.3$), a finding we return to in the Discussion. **Figure 2c** displays a summary of these results.

After confirming a difference between bCFS and reCFS thresholds, we next compared suppression depth measured using different image types. We repeated the analysis with the additional exploratory factor of image type (face vs object) in a 2 x 2 x 2 repeated-measures design (threshold, procedure, image type). We again found significant main effects of threshold ($F(1,19) = 50.39$, $p < .001$, $\eta_p^2 = .73$), and a threshold x condition interaction ($F(1,19) = 41.19$, $p < .001$, $\eta_p^2 = .68$), but non-significance for the effect of image type ($p = .26$).

We quantified the evidence for this null-effect on suppression depth with a subsequent Bayesian model comparison. A Bayesian repeated-measures ANOVA (2 x 2; procedure x image type on suppression depth) found that the best model to explain suppression depth included the main effect of procedure ($BF_{10} = 3231.74$), and weak evidence/data insensitivity for image type ($BF_{10} = 0.37$). This indicates that the data was insensitive as to whether image-type was better at predicting suppression depth than the null model. In other words, there is a large disparity in contrast between targets breaking and re-entering CFS, but the magnitude of this disparity is most likely the same for objects and for faces. This potentially important finding is the focus of our next Experiment.

Experiment 2

Experiment 1 disclosed that bCFS thresholds were not equivalent to reCFS thresholds, and demonstrated that the suppression depth of images could be quantified in an image-specific manner. Furthermore, Experiment 1 showed that suppression depth could be measured rapidly using the tCFS procedure and did not differ between faces and objects. In Experiment 2, we tested whether the constant suppression depth obtained in Experiment 1 for two image types would replicate across a larger variety of image categories.

We measured suppression depth for faces, objects, linear gratings, phase scrambled images, and radial/concentric patterns using the tCFS method. All have been used to investigate bCFS thresholds before (Stein, 2019). We reasoned that faces and objects are familiar, meaningful stimuli processed widely throughout the visual hierarchy. Gratings and phase-scrambled images, on the other hand, comprise simpler, meaningless stimuli devoid of perceptual relevance. Phase-scrambled images were created from the object stimuli by randomising their phase spectra, rendering the images unrecognizable (e.g., Piotrowski & Campbell, 1982; Yu & Blake, 1992). These images thus served as controls for the regular stimuli, since both ordinary and phase-scrambled images have approximately the same Fourier energy spectra. Finally, polar patterns (radial and concentric gratings) were included because they have robust structural coherence that is registered by extrastriate visual areas in the ventral stream (Wilkinson et al., 2000), but are lacking in semantic meaning (Hong, 2015).

A 2 x 5 repeated-measures ANOVA revealed a significant main effect of threshold (bCFS vs reCFS; $F(1,17) = 133.79$, $p < .001$, $\eta_p^2 = .89$), and image type ($F(4,68) = 13.45$, $p < .001$, $\eta_p^2 = .44$). Critically however, there was no significant interaction between thresholds and image type ($p = .98$), indicating that the relationship between bCFS and reCFS thresholds was invariant across image categories. A Bayesian repeated-measures ANOVA (1 x 5, effect of image categories on suppression depth), confirmed strong evidence in favour of the null hypothesis (BF_{01} =20.30).

This result is plotted in **Figure 3**, which clearly shows differences in bCFS thresholds (blue symbols in **Figure 3a**) over image type (1 x 5 repeated-measures ANOVA; $F(4,68) = 16.29$, $p < .001$, $\eta_p^2 = .49$), as has been reported in many studies. Scrambled noise images, for example, yield breakthrough thresholds 5.3 dB higher than do face images, and linear gratings breakthrough thresholds are 3.0 dB higher than polar gratings. Critically, **Figure 3** also shows that reCFS thresholds exhibit the same pattern of differences over image type (red symbols in **Figure 3a**): and as confirmed by our Bayesian model comparison, the depth of suppression is constant across all image categories.

Replicating the result of Experiment 1, approximately 15 dB of suppression depth was observed in Experiment 2 (**Fig. 3b**), which was practically identical across image types (Faces, M = 14.35 (SD = 5.64); Objects, M = 14.61 (SD = 6.07); Gratings, M = 14.88 (SD = 5.55); phase-scrambled images, M = 14.70 (SD = 5.39); polar patterns, M = 14.69 (SD = 6.50). A repeated-measures ANOVA confirmed that suppression depth did not differ across image categories ($F(4,68)= 0.1$, p = .98).

Experiment 3

Experiments 1 and 2 introduced the tCFS method and, using that new method, demonstrated that bCFS thresholds vary depending on target type, as many previous bCFS studies have shown. Importantly, reCFS thresholds varied in parallel with bCFS thresholds, which when expressed in terms of suppression depth, reveals that depth of suppression is strikingly uniform across target image categories in CFS. This uniformity of suppression depth could indicate that neural events mediating CFS suppression transpire within a common visual mechanism, one that is not selective for image type, complexity or semantic meaning, over a wide range of stimulus configurations. This view is compatible with popular models of binocular rivalry built around the concept of reciprocal inhibition and neural adaptation (Alais et al., 2010; Kang & Blake, 2010; McDougall, 1901), as well as with more recent Bayesian-inspired inference-based models in which perceptual alternations in dominance are triggered by accumulating residual error signal associated with competing stimulus interpretations (Hohwy et al., 2008). As pointed out elsewhere (Blake, 2022), steadily increasing error signal effectively plays the same role as does steadily decreasing inhibition strength caused by neural adaptation in reciprocal inhibition models.

In the context of the tCFS method, the steady increases and decreases in the target's *actual* strength (i.e., its contrast) should impact its emergence from suppression (bCFS) and its reversion to suppression (reCFS) as it competes against the mask. Whether construed as a consequence of neural adaptation or error signal, we surmise that these cycling state transitions defining suppression depth should be sensitive to the rate of contrast change of the monocular target. Expressed in operational terms, the depth of suppression should covary with the rate of target change. Experiment 3 tested this supposition using three rates of contrast change.

A 3 x 2 x 4 repeated measures ANOVA compared three rates of contrast change (slow, medium, fast), on both thresholds (bCFS, reCFS) across four image categories (face, object, grating, phase scrambled) using the tCFS paradigm. There was a significant main effect of threshold ($F(1,16)$ = 116.56, $p < .001$, $\eta_p^2 = .88$) again indicating that bCFS and reCFS contrasts differ. There was also a significant main effect of image type ($F(3,48) = 9.40$, $p < .001$, $\eta_p^2 = .37$), again with no interaction with threshold (p = .19). This result indicates that bCFS and reCFS thresholds vary in tandem regardless of image type. This null-effect of image-type was again confirmed with a Bayesian model comparison (3 speed x 4 image categories on suppression depth), demonstrating moderate support for the null effect of image category (BF_{01}= 4.06). Critically, there was a significant interaction between rate of contrast change and thresholds ($F(2,32) = 128.60$, $p < .001$, $\eta_p^2 = .89$), as

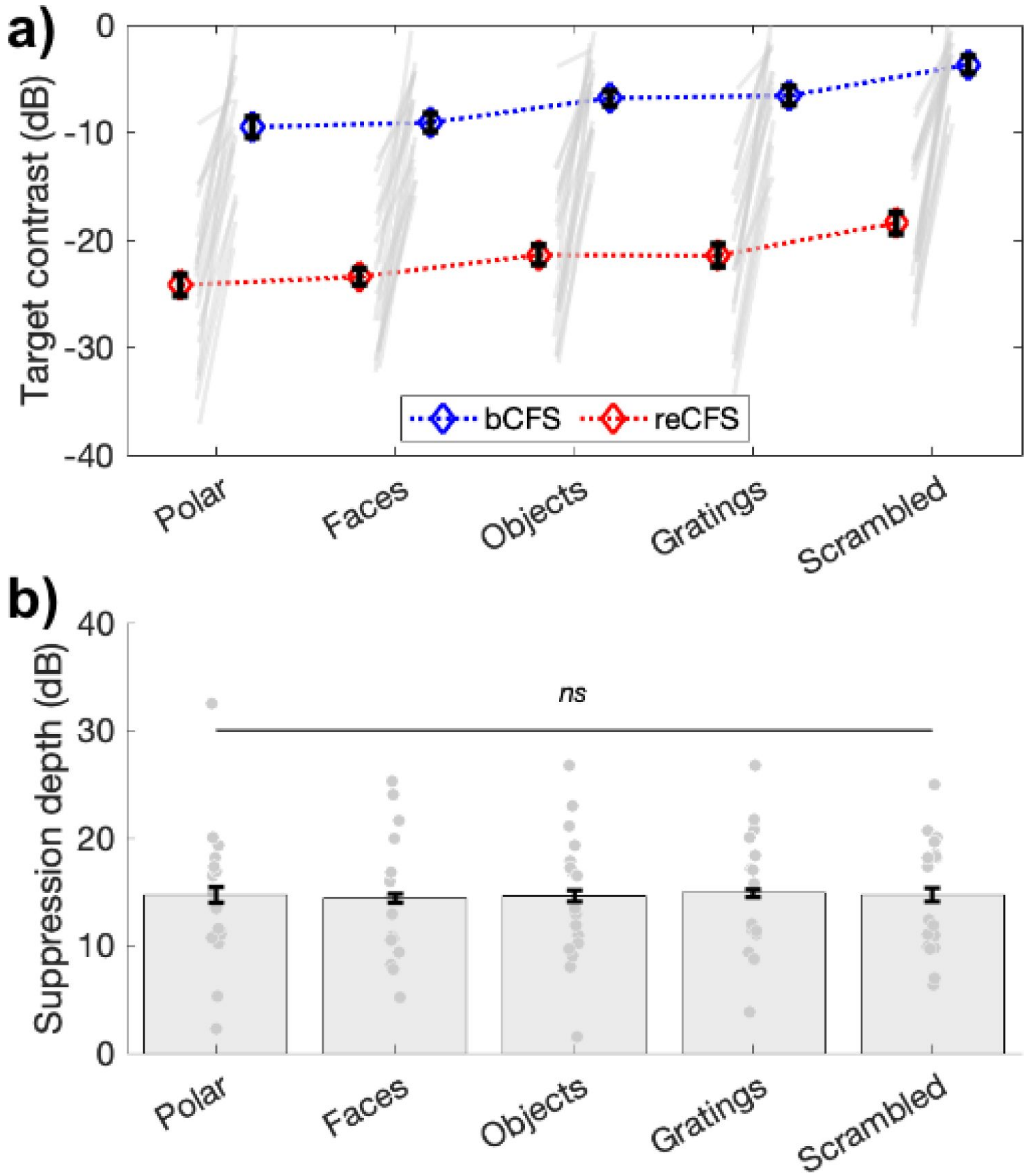


Figure 3.

Suppression depth is uniform across image categories.

a) bCFS and reCFS thresholds by image type. Blue and red diamonds display the mean across participants, and error bars plot ±1 SEM corrected for within participant comparisons (Cousineau, 2005). Grey lines link thresholds per participant, per image type. For visualization, we have linked the bCFS and reCFS thresholds with broken lines, to better indicate that both do vary according to image category. **b)** The relative difference in contrast between bCFS and reCFS thresholds is the same across image categories.

expected, indicating that the difference between bCFS and reCFS thresholds (i.e., suppression depth) depended on the target's rate of contrast change. **Figure 4** displays a summary of these results (averaged across image types), showing that as the rate of contrast change increases, so does suppression depth (Slow *M* = 9.64 dB, *SD* = 4.37, Medium *M* = 14.6 dB, *SD* = 5.43; Fast *M* = 18.97 dB, *SD* = 6.93). **Supplementary analyses** confirmed that these differences in suppression depth were not driven by fixed rates of perceptual alternation across the three levels of rate of contrast change (**Figure 4c** and **Supplementary Figure 1**)

Perceptual switches during tCFS are described by a damped harmonic oscillator

The results of Experiment 3 demonstrated that when the opportunity for target adaptation is increased, as when the target's rate of contrast change was slow, that suppression depth is reduced and a smaller contrast decrease is needed for a visible target to reenter CFS (see **Figure 4a**). One possible account for this relates to the balance of excitation/inhibition in neural systems, which have been particularly fruitful models of interocular competition (Alais et al., 2010; Li et al., 2017). In these models, adaptation over time is a critical parameter governing changes in visual consciousness (Alais et al., 2010), which motivated us to explore in our final analysis whether suppression depths also fluctuated over time. Accordingly, our final analysis sought to model the temporal nature of perceptual switches during tCFS, to understand whether a balance of excitation and inhibition may be contributing to the sequential contrast thresholds that govern target visibility.

For this analysis, a key dependent variable is the contrast difference between sequential thresholds (i.e., from bCFS to reCFS, or reCFS to bCFS). As the number of thresholds was the same in each trial, we averaged each threshold over observers to obtain a sequence of mean thresholds that preserved the order across the trial (e.g. average reCFS threshold at response 1, average bCFS threshold at response 2, average reCFS threshold at response 3 etc). Importantly, pooling across the threshold order rather than each participant's time series avoids smearing the data due to observers differing in their perceptual durations (**cf. Supplementary Figure 1**). **Figure 5a** displays the mean result separately for each target rate of change condition. To investigate the balance between bCFS and reCFS thresholds, we calculated the absolute change in contrast between sequential thresholds, as plotted in **Figure 5b**. These sequential estimates of suppression depth show marked fluctuations early in each trial, followed by a stabilisation to the grand average suppression depth for each rate of contrast change (Slow ~10 dB, Medium ~ 15 dB, Fast ~ 19 dB).

We next tested whether these sequential changes in suppression depth could be described by models of excitation and inhibition. For each rate of change condition, we compared the goodness of fit of three models: a simple harmonic oscillator, a damped harmonic oscillator, and a cubic polynomial model. We assessed the relative goodness of fit using the change in Bayesian Information Criterion (BIC) between models (see **Methods**).

As can be appreciated in **Figure 5c**, sequential changes in suppression depth were well described by the damped harmonic oscillator model of excitation and inhibition, which well captured the modulations early in the trial. For each rate of target contrast change, the damped harmonic oscillator model was the superior fit to the data (Slow contrast change, R^2 = 0.68, BIC = -1847.2; Medium contrast change, R^2 = 0.63, BIC= -2125.29; Fast contrast change, R^2 = 0.36, BIC= -1041.29). In each case, the change in Bayesian Information Criterion between the damped harmonic oscillator and the next best fitting cubic polynomial model was large (Slow contrast change, ΔBIC = -1072.88; Medium contrast change, ΔBIC = -781.5; Fast contrast change, ΔBIC = -97.06). **Supplementary Table 1** displays the assessments of each model fit for each rate of change condition.

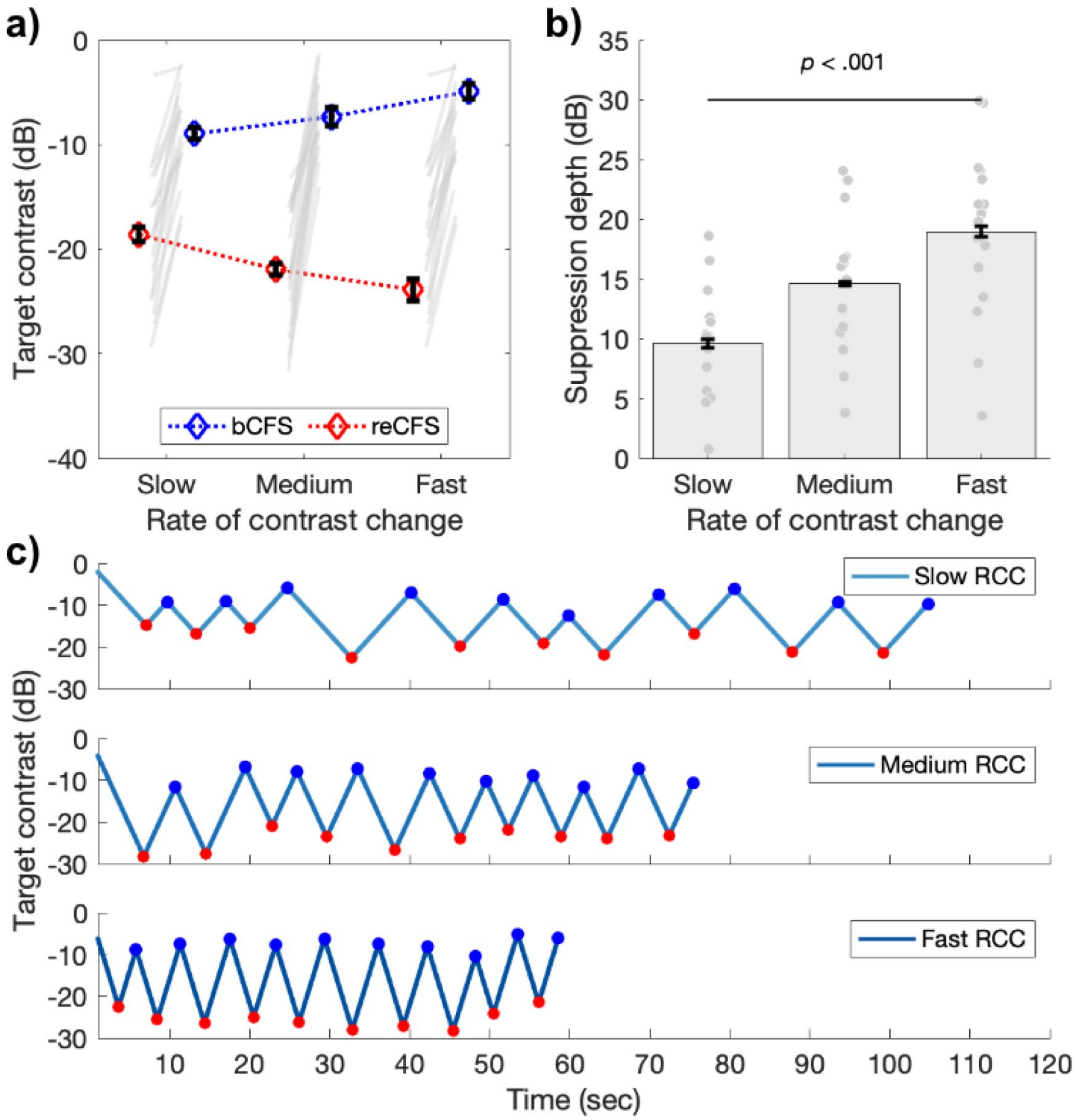


Figure 4.

Suppression depth is greater with less time for adaptation.

a) bCFS (blue) and reCFS (red) thresholds collected during tCFS with three rates of contrast change (RCC). Figure elements are the same as in **Figure 3a**. **b)** Suppression depth increases when the rate of contrast change increases during tCFS. All error bars correspond to ±1 SEM corrected for within participant comparisons (Cousineau, 2005). **c)** Example trials at each rate of contrast change from a single participant. Red markers indicate reCFS responses, blue markers show bCFS.

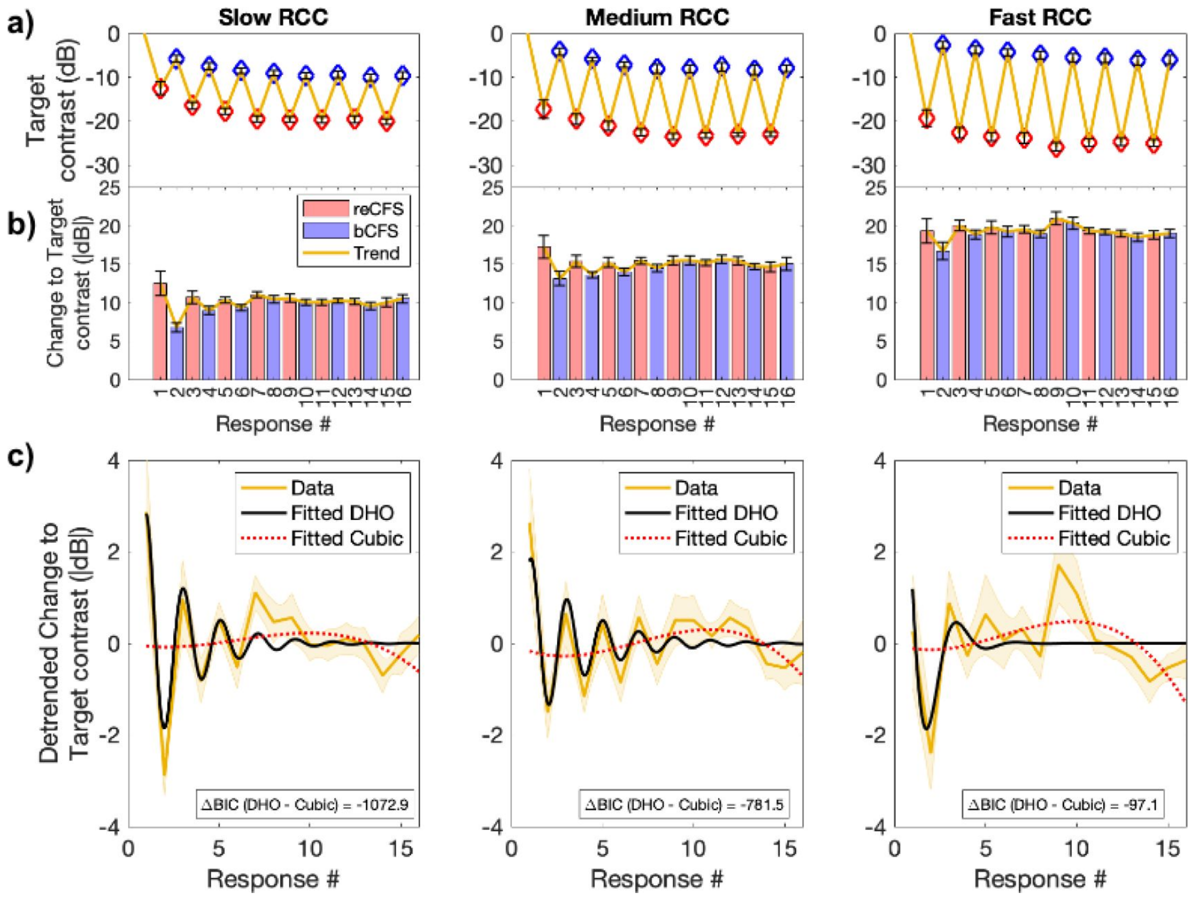


Figure 5.

Suppression depth over time is well described by a damped harmonic oscillator.

a) Top row: Mean bCFS (blue) and reCFS (red) thresholds averaged by threshold order over the trial. Each column displays the average for slow, medium and fast rate of contrast change (RCC), respectively. **b) Middle row.** Absolute change in target contrast between successive thresholds (i.e., suppression depth). Red bars indicate the decrease in target contrast needed for a visible target to reenter CFS. Blue bars indicate the increase in contrast for an invisible target to break CFS. **c) Bottom row:** Yellow lines and shading plot the average change in suppression depth between successive thresholds. The data in each RCC condition is best fit by a damped harmonic oscillator (DHO) model shown in black. The change in Bayesian Information Criterion relative to the next best (cubic polynomial) model is displayed in each panel. All error bars and shading denote ±1 SEM corrected for within participant comparisons (Cousineau, 2005).

The damped harmonic oscillator has been proposed to capture the response of neural populations governed by excitation/inhibition balance after external perturbation, with a given rate of decay. We return to the interpretation of these models in the Discussion.

Discussion

This study introduces a new CFS methodology that indexes suppression depth based on a participant's continuous report of the visibility status of a monocularly viewed target that steadily waxes and wanes in contrast, while the other eye views a CFS mask that forces the target into and out of suppression. The key to the technique, dubbed tracking CFS (tCFS), is that the participant's responses control when the reversals in the direction of contrast change occur: for example, a visible target initially decreases from high contrast until the participant reports the target's disappearance from awareness, at which time the target begins increasing in contrast until it again achieves awareness, and so on in an ongoing cycle. By tracking target visibility in this way, the method produces breakthrough thresholds (as in bCFS), but also yields measures of suppression thresholds(reCFS). By measuring the relative difference between these two thresholds, one can derive a rational index of suppression depth that, in turn, allows critical evaluation of whether suppression depth varies for different image categories (e.g., faces vs gratings). Experiment 1 introduced and validated the tCFS method for measuring suppression depth. Experiment 2 applied tCFS to images from different categories and found that suppression depth was invariant across a set of different types of images, regardless of their complexity, familiarity or salience. Experiment 3 manipulated suppression depth by varying the rate of target contrast change, providing presumptive evidence consistent with particular interpretation of the neural bases of the tCFS procedure. The following sections elaborate on each of these points.

The tCFS method offers two important advances for studying visual processing outside of awareness. First, it is fast and efficient. The data in **Figure 2b**, for example, show that 90 seconds is sufficient to collect a robust set of data comprising 16 thresholds, eight each for bCFS and reCFS. The second advantage is that by providing easy quantification of breakthrough and suppression thresholds, tCFS allows the calculation of a rational index of strength of suppression for evaluating whether certain categories of images (e.g., faces) receive prioritized processing, a controversial issue within the CFS literature. We will have more to say about claims of preserved visual processing despite suppression, and claims of unconscious processing more generally in a moment (see ***No effect of image category on suppression depth***).

Thresholds for breaking and entering suppression quantify suppression depth

In Experiment 1, we used the tracking CFS method to measure bCFS and reCFS contrast thresholds, and compared them to those obtained using discrete unidirectional contrast changes – a series of measures with increasing target contrast to obtain bCFS thresholds as conventionally done, and also a series with decreasing target contrast to measure suppression (reCFS) thresholds. For both conditions, significant differences between bCFS and reCFS thresholds were observed. This difference indicates that suppression is not a passive process where a given contrast threshold determines a narrow awareness/suppression border. Instead, there is a contrast range (i.e., suppression depth) between awareness and suppression. This is consistent with models of interocular suppression involving mutually inhibitory left- and right-eye processes. The fact that binocular rivalry produces a significant degree of suppression depth is well known in that literature (Blake & Camisa, 1979; Nguyen et al., 2003) but is rarely considered in CFS studies[2] where the focus is typically on the breakthrough threshold for awareness.

Intuitively, the average contrast threshold for reCFS should be lower than for bCFS, yet in the discrete conditions there were some participants who showed the inverse effect (*n* = 4; **Figure 2c**). One possibility is that saccades, blinks, or other oculomotor reflexes that differentially impact transitions during interocular rivalry (van Dam & van Ee, 2006a, 2006b) might have influenced the discrete bCFS and reCFS trials at separate times. Another possibility is that by using a blocked design in the discrete trials, a participant's motivation or attention to task might have changed in the time elapsed between recording thresholds in bCFS and reCFS blocks. These possibilities highlight inherent advantages and controls of the tCFS procedure, for which no participant showed an inverse effect: bCFS and reCFS thresholds are recorded in alternation, thus each threshold judgment is relative to the previous judgment on the same image, recorded a matter of seconds (rather than minutes) prior. During tCFS, bCFS and reCFS tasks alternate, which helps maintain a level of engagement as the task is never repeated. Alternating between bCFS/reCFS tasks also means that any adaptation occurring over the trial will occur in close proximity to each threshold, as will any waning of attention. The benefit being that bCFS and reCFS thresholds are measured under closer conditions in continuous trials, compared to discrete ones. Long periods of target invisibility that can occur in typical bCFS studies when the target is raised from near-zero contrast are also avoided, as target contrast hovers around the visibility/invisibility thresholds. As **Figure 2c** shows, tCFS produces an increased size of suppression depth compared to discrete trials. Moreover, it can be administered quickly, and provides threshold measures with less variance.

As an aside, the existence of distinctly different, complementary transition thresholds for bCFS and reCFS is reminiscent of the behavior termed hysteresis: a property of dynamical systems wherein output values, rather than being solely governed by corresponding input values, also exhibit lags or delays based on the valence of continuous changes in the input values. Examples of hysteresis in visual perception include transitions between binocular fusion and binocular rivalry (Anderson, 1992; Buckthought et al., 2008; Julesz & Tyler, 1976), perception of motion direction in random-dot cinematograms (Williams et al., 1986), and repetition priming in perception of bistable configurations (Pastukhov et al., 2015). To paraphrase Maglio and Polman (Maglio & Polman, 2016), hysteresis can be construed as a form of memory whereby prior states influence the persistence of current states into the future.

No effect of image category on suppression depth

Having demonstrated a difference between bCFS and reCFS thresholds using the tCFS procedure, Experiment 2 compared suppression depth across five different image categories. As noted in the Introduction, a number of previous studies have interpreted differences in bCFS thresholds (or suppression durations) for different categories of images without taking into account thresholds for *inducing* suppression, which we believe is an important piece of information necessary for calculating suppression depth. In this paper, we applied the tCFS method to assess whether bCFS thresholds differed among several image categories and, as well, whether category-specific differences in suppression depth would be obtained when reCFS thresholds were also included in the equation. As an important prerequisite for asking this question, our bCFS thresholds indeed did replicate the often reported finding that certain image types break out of suppression into awareness at lower contrasts than do others (see **Figure 3a**). For example, bCFS thresholds for faces were lower than bCFS thresholds for phase-scrambled images by 5.3 dB. Critically, however, while bCFS thresholds varied with image type, the reCFS thresholds for those and, indeed, for all images was approximately 15 dB lower than bCFS, *regardless of image type*. In other words, all five of the image categories we tested, regardless of complexity or familiarity, produced a constant depth of suppression averaging about 15 dB (see **Fig. 3b**), even though their bCFS thresholds varied.

As a reminder, we explicitly tested image types that in other studies have shown differential susceptibility to CFS attributed to some form of expedited unconscious processing. Nevertheless, one could argue that our failure to obtain evidence for category specific suppression depth is based on the limited range of image categories sampled in this study. We agree it would be informative to broaden the range of image types tested using tCFS to include images varying in familiarity, congruence and affect. We can also foresee value in deploying tCFS to compare bCFS and reCFS thresholds for visual targets comprising physically meaningless 'tokens' whose global configurations can synthesise recognizable perceptual impressions. To give a few examples, dynamic configurations of small dots varying in location over time can create the compelling impression of rotational motion of a rigid, 3D object (structure from motion) or of a human engaged in given activity (biological motion) (Grossmann & Dobbins, 2006; Watson et al., 2004). These kinds of visual stimuli are associated with neural processing in higher-tier visual areas of the human brain, including the superior occipital lateral region (e.g., (Vanduffel et al., 2002)) and the posterior portion of the superior temporal sulcus (e.g., (Grossman et al., 2000)). These kinds of perceptually meaningful impressions of objects from rudimentary stimulus tokens are capable of engaging binocular rivalry. Such stimuli would be particularly useful in assessing high-level processing in CFS because they can be easily manipulated using phase-scrambling to remove the global percept without altering low-level stimulus properties. In a similar vein, small geometric shapes can be configured so as to resemble human or human-like faces, such as those used by (Zhou et al., 2021)[3]. These kinds of faux faces could be used in concert with tCFS to compare suppression depth with that associated with actual faces.

Next we turn to another question raised about our conclusion concerning invariant depth of suppression: If certain image types have overall lower bCFS and reCFS contrast thresholds relative to other image types, does that imply that images in the former category enjoy "preferential processing" relative to those in the latter? Given the fixed suppression depth, what might determine the differences in bCFS and reCFS thresholds? **Figure 3** shows that polar patterns tend to emerge from suppression at slightly lower contrasts than do gratings and that polar patterns, once dominant, tend to maintain dominance to lower contrasts than do gratings and this happens even though the rate of contrast change is identical for both types of stimuli. But while rate of contrast change is identical, the neural responses to those contrast changes may not be the same: neural responses to changing contrast will depend on the neural contrast response functions (CRFs) of the cells responding to each of those two types of stimuli, where the CRF defines the relationship between neural response and stimulus contrast. CRFs rise monotonically with contrast and typically exhibit a steeply rising initial response as stimulus contrast rises from low to moderate values, followed by a reduced growth rate for higher contrasts. CRFs can vary in how steeply they rise and at what contrast they achieve half-max response. CRFs for neurons in mid-level vision areas such as V4 and FFA (which respond well to polar stimuli and faces, respectively) are generally steeper and shifted towards lower contrasts than CRFs for neurons in primary visual cortex (which responds well to gratings). Therefore, the effective strength of the contrast changes in our tCFS procedure will depend on the shape and position of the underlying CRF, an idea we develop in more detail in **Supplementary Appendix 1**, comparing the case of V1 and V4 CRFs. Interestingly, the comparison of V1 and V4 CRFs shows two interesting points: (i) that V4 CRFs should produce much lower bCFS and reCFS thresholds than V1 CRFs, and (ii) that V4 CRFs should produce more suppression than V1 CRFs. Our data do not support either prediction: **Figure 3** shows that bCFS and reCFS thresholds are very similar for all image categories and suppression depth is uniform. There is no room in these results to support the claim that certain images receive "preferential processing" or processing outside of awareness, although there are many other kinds of images still to be tested and exceptions may potentially be found. As a first step in exploring this idea, one could use standard psychophysical techniques (e.g., (Ling & Carrasco, 2006)) to derive CRFs for different categories of patterns and then measure suppression depth associated with those patterns using tCFS.

In a similar vein, it's natural to wonder whether this non-selectivity of CFS depth of suppression applies to binocular rivalry suppression, too. Blake and Fox (Blake & Fox, 1974) concluded that rivalry suppression is non-selective based on a task where observers were unable to notice large changes in the spatial frequency or orientation of a suppressed grating. On the other hand, Alais and Melcher (Alais & Melcher, 2007) found that the detectability of a brief, monocular probe presented to an eye during rivalry varied depending on the ‘complexity’ (e.g., grating vs face) of the stimulus being probed, with suppression being greater for complex images. Tsuchiya et al. (Tsuchiya et al., 2006) found that detection of a brief test probe was much more difficult to detect when presented to an eye during suppression phases of CFS compared to binocular rivalry. In a similar vein, durations of suppression phases associated with CFS are considerably longer than those associated with rivalry (~15x longer, in the study by Blake et al., 2019). A clear next step will be to apply a variant of the tCFS paradigm to binocular rivalry to assess the uniformity of rivalry suppression depth based on stimulus complexity.

Turning to a methodological issue, an important caveat for interpreting suppression depth during tCFS is that bCFS thresholds will be slightly overestimated due to the brief reaction time delay between the perceived transition and execution of the motor response signalling that event (a problem for most bCFS studies). By the same token, reCFS thresholds will be slightly underestimated because of this response delay. These disparities between transition times and the responses to them lead to a slight inflation of suppression depth. For example, if we assume an average reaction time of 500 ms for appearance and disappearance events, then suppression depth will be inflated by ~4.2 dB at the rate of contrast change used in Experiments 1 and 2 (.07 dB per frame at 60 fps). This cannot account for suppression depth in its entirety, which was many times larger at approximately 14 dB across image categories. We have no reason to suspect that reaction-times would differ when reporting on the appearance or disappearance of different image categories under CFS, and indeed found no significant evidence for an interaction between thresholds and image categories in our analyses. This leaves a constant suppression depth of approximately 14 dB to be explained, and the value of comparing between image categories remains. In Experiment 3, the rate of contrast change varied which led to corresponding changes in suppression depth, which we note could also not be attributed to a reaction-time delay (**Supplementary Figure 1**). Using the same assumptions of a 500 ms response time delay, this would predict a suppression depth of 2.1 dB, 4.2 dB and 6.3 dB for the slow, medium and fast ramp speeds respectively. However, this difference cannot account for the size of the effects (*Slow* 9.64 dB, *Medium* 14.6 dB, *Fast* 18.97 dB). The difference in suppression depth based on reaction-time delays (± 2.1 dB) also does not match with our empirical data (*Medium* - *Slow* = 4.96 dB; *Fast* - *Medium* = 4.37 dB).

Previous research has attributed faster CFS breakthrough (equivalently, lower contrast) to unconscious processing of suppressed images (Gayet et al., 2014; Mudrik et al., 2011). As the current study found uniform suppression depth for all tested images, even though bCFS thresholds varied, it is clear that differences in bCFS thresholds alone should not be interpreted in terms of expeditious unconscious processing of semantically relevant images. Indeed, if image categories such as faces were processed unconsciously, they reasonably should be harder to re-suppress, and thus have a smaller suppression depth compared to neutral stimuli (see **Figure 1**) – which was not the case.

As an alternative to lower bCFS thresholds being due to unconscious processing of images with relevant semantic content, such images (here, faces and objects) may break suppression at lower contrasts because they are particularly rich in low-level feature content that promotes image salience (e.g., (Itti & Koch, 2000)). For example, faces and objects could be more salient due to peaks in local image contrast (Parkhurst & Niebur, 2004), contour integration (Kapadia et al., 2000), closed curvilinear form (concavity: (Schmidtmann et al., 2015), and phase aligned spatial frequency spectra (Maehara et al., 2009). The combination of these image properties plausibly render images such as faces and objects particularly salient within early stages of visual processing and thus lead to lower bCFS thresholds than those measured for less salient stimuli such as gratings or scrambled noise. Moreover, this derivation of salience is purely stimulus-based and arises without regard to semantic implications. This possibility, which has been raised by others (Gayet et al., 2014; Moors, 2019; Moors et al., 2016, 2017; Moors & Hesselmann, 2018), has appeal on grounds of parsimony. With the advent of tCFS, it is now possible to measure bCFS and reCFS for salience-indexed stimuli to learn the extent to which stimulus-based salience impacts suppression depth.

Some caution is warranted here, however. It is not clear that all variation in bCFS thresholds can be explained by low-level image properties. There may be important high-level factors that also contribute to the salience of a given target image that make it visible at lower contrasts than other images (Gayet et al., 2014; Jiang et al., 2007; Mudrik et al., 2011; Yang et al., 2007). For example, faces provide essential social information and we are very highly attuned to them. Face images may therefore be salient at lower contrasts than other images such as random noise for high-level reasons specific to face processing. However, given there is a parsimonious account of low bCFS thresholds for faces in terms of low-level image properties, this would need to be established experimentally, perhaps using face inversion (Matsuyoshi et al., 2015) or contrast reversal (Liu-Shuang et al., 2022), manipulations that differentially impact visual processing of faces compared to other object categories This matter is still open and ripe for further experimental evidence, but our current findings add support to the argument that faces may become visible in CFS at lower contrasts for reasons unrelated to special access to awareness or partial processing during suppression..

A hybrid-model might therefore be needed for a full account of CFS, similar to those proposed for binocular rivalry (Cao et al., 2021; Wilson, 2003). Based on our results here, we imagine a hybrid model in which relative suppression depth for a given image arises from low-level interocular mutual inhibition acting equivalently on any kind of image (yielding the uniform suppression depth we observe), and the absolute level of breakthrough threshold could be impacted by high-level salience (e.g., (Hesse & Tsao, 2020)). Careful manipulation of low- and high-level properties, in combination with the tCFS method, should be able to test this model, as discussed earlier.

Suppression depth is modulated by rate of contrast change

Experiment 3 varied the rate of target contrast change with the expectation that this would alter the magnitude of adaptation during tCFS. We predicted that a faster contrast change would reduce the opportunity for adaptation to accrue, thereby requiring a greater change in contrast to overcome suppression during CFS. Similarly, a slower rate of change should increase the opportunity for adaptation, resulting in the inverse effect. We observed strong modulations of suppression depth based on the rate of contrast change, confirming these predictions (**Figure 4**). Follow-up analyses confirmed that all three rates of contrast change had distinct percept duration times (**Supplementary Figure 1**), indicating that the differences in suppression depth we observed were not due to an artefact such as participants responding with a fixed inter-response interval, which would spuriously increase suppression depth for a fast rate of change.

Damped harmonic oscillator model

We modelled the changes in contrast between successive bCFS and reCFS thresholds over a trail and found that a damped harmonic oscillator (DHO) provided an excellent fit to these sequential estimates of suppression depth. The applicability of this model is noteworthy for a number of reasons. First, in neuroscience, the DHO model provides a valuable mathematical framework for understanding the dynamics of neural systems and their responses to external stimuli, particularly with regard to the interplay between excitation and inhibition (Freeman, 1961; Hodgkin & Huxley, 1952; Spyropoulos et al., 2022). In the present context, the high starting contrast of the suprathreshold target in tCFS trials is analogous to the external perturbation. The asymptotic differences in thresholds over time are reminiscent of both earlier (Wilson, 2003), and more recent computational models (Cao et al., 2021) of interocular competition, models proposing that changes to visual awareness are driven by an out-of-equilibrium cortical network. We note that the locus of competing neural ensembles could reside in early visual stages (Alais et al., 2010; Lankheet, 2006; Li et al., 2017), late stages (Hohwy et al., 2008) or across hierarchical (Cao et al., 2021; Wilson, 2003) levels of visual processing. Although it is beyond the scope of the present work, future studies could vary the starting conditions of the tCFS procedure, or manipulate higher-order influences such as attention and expectation to examine whether the return to equilibrium we have revealed conforms to the predictions of competing models.

Future Directions

The tCFS method equips researchers with a convenient method to measure bCFS and reCFS thresholds, and thus suppression depth. We have used tCFS here to establish that a uniform suppression depth exists across image categories, and that differences in bCFS thresholds alone cannot provide strong evidence for unconscious processing. Many substantive questions remain. For example, the depth of interocular suppression is reported to partially depend on spatial feature similarity between the competing images (Alais & Melcher, 2007; Drewes et al., 2023) and their temporal frequency (Han et al., 2018; Han & Alais, 2018). These factors could be parametrically varied to examine specifically whether they modulate bCFS thresholds alone, or whether they also cause a change in suppression depth by asymmetrically affecting reCFS thresholds. Previous findings can easily be revisited, such as results showing that bCFS varies with manipulations of semantic content (e.g., face inversion, or manipulating a face's emotion), results which form part of the claimed evidence for expedited unconscious processing of certain suppressed images.

Conclusion

Across three experiments we have introduced the tCFS method and shown that traditional evidence for unconscious processing – based on differences in the threshold to reach awareness (bCFS threshold) – provide only half the story. Misleading conclusions about unconscious processing must be supported by measures of suppression depth, which can be calculated as the difference between both breakthrough (bCFS) and suppression (reCFS) thresholds. Using the tCFS method we have measured these thresholds, and found uniform suppression depth across five image five categories. Notably, this uniform suppression depth is increased with reduced opportunity for target image adaptation, as is the case when target contrast changes rapidly. Collectively, the three tCFS experiments refute existing claims of high-level semantic information or target complexity influencing the depth of unconscious processing during interocular suppression. Future findings may yet confirm differences in suppression depth in certain circumstances, yet this will require measurement of both breakthrough and suppression thresholds to demonstrate the requisite changes in suppression depth.

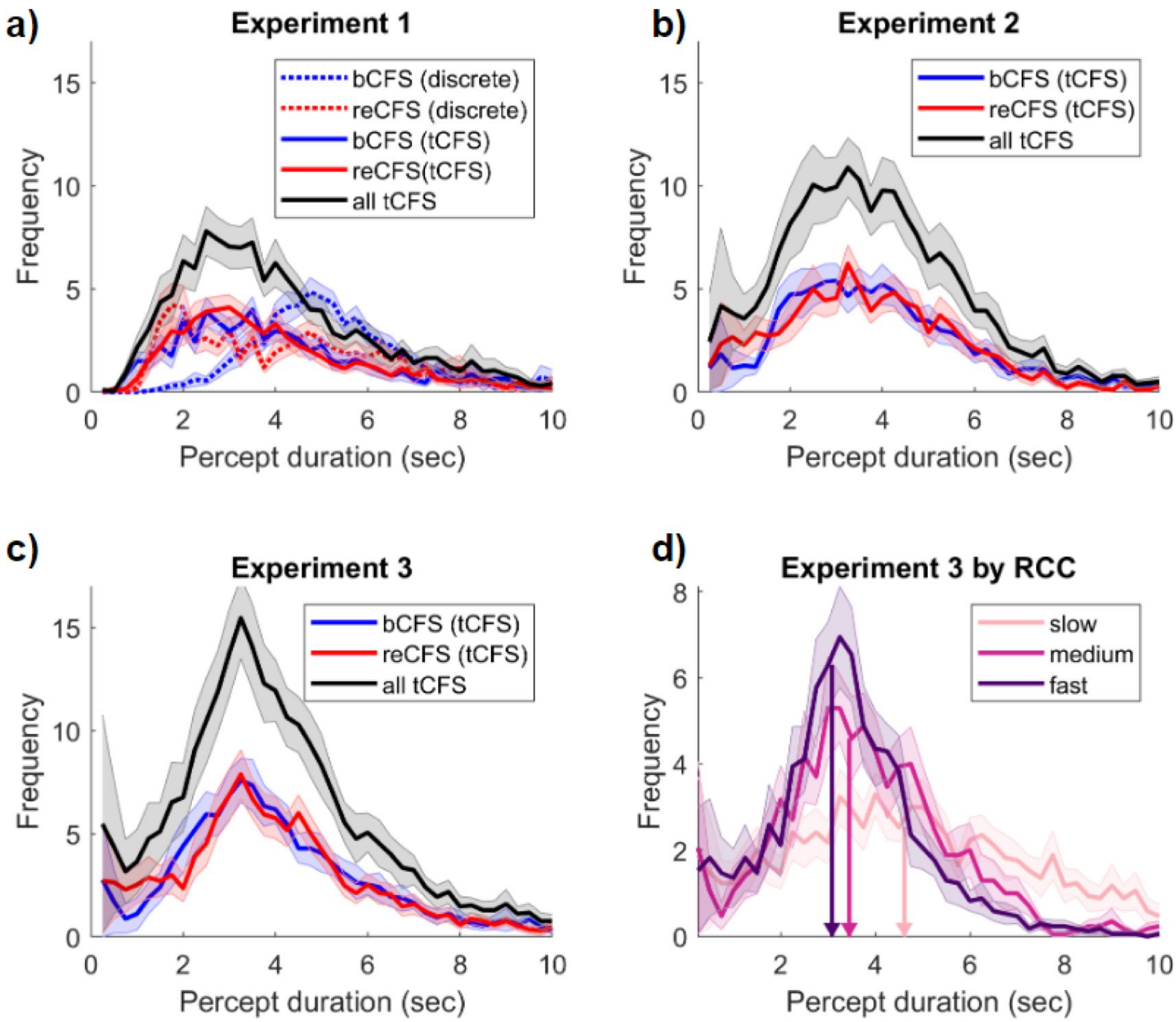
Supplementary Material

We performed additional analyses to rule out an alternative explanation for the increased suppression durations demonstrated in Experiment 3. We reasoned that if alternations between bCFS and reCFS were happening with a regular periodicity, such that responses were made every 1 second (for example), then these consistent responses could result in smaller suppression thresholds when the rate of contrast change was slow, as we have observed. Similarly, larger suppression thresholds would be measured if the same 1 second interval had elapsed while the rate of contrast change was fast. Inspection of the raw tCFS time-series qualitatively indicated that perceptual durations were varying with the rate of target contrast change **(Figure 4c).** To test this possibility, we compared the group average perceptual durations across all experiments, to test whether the average duration of percepts was the same despite different rates of contrast change. **Supplementary Figure 1** displays the results of this analysis. The histograms of perceptual durations for Experiments 1 (all tCFS median *M* = 3.83, *SD* = 1.66) and Experiment 2 (*M* = 3.48, *SD* = 1.36) show similar means and distributions, with no significant difference between them ($t(36) = 0.72$, $p = .48$). This is unsurprising given their similar design and matched rate of contrast change. In Experiment 3, however, the distribution of percept durations is shown to vary by rate of contrast change. With shorter median percept durations for fast rates of contrast change (*M* = 3.08, *SD* = 1.07), and slower percept durations for slow rates of contrast change (*M* = 4.61, *SD* = 2.05) compared to medium (*M* = 3.45, *SD* = 1.29). A repeated measures ANOVA confirmed that median percept durations varied by rate of contrast change ($F(2,32) = 30.89$, $p < .001$, $\eta_p^2 = .66$).

Supplementary Appendix 1: Difference thresholds as a measure of suppression depth and the role of contrast response functions

One question raised in review concerned using a decibel contrast scale and the calculation of suppression depth as the difference between breakthrough and suppression thresholds. The justification for this is twofold. First, neurons in early visual cortex exhibit a logarithmic-like response to contrast that grows rapidly at low contrasts and then saturates at higher contrasts. Data from single V1 neurons show that these contrast response functions (CRFs) to linear contrast can be very adequately described by fitting a logarithmic curve, but not by linear or power functions (Albrecht & Hamilton, 1982). Consistent with a logarithmic response, perceptual thresholds for contrast increments tend to be a constant proportion of the base contrast (i.e, Weber's law holds). For these reasons, logarithmically scaled contrast changes should therefore produce approximately linear changes in perceived contrast and should be used when ramping contrast in CFS procedures. Second, once contrast is log-transformed to decibels, the difference calculation used to obtain suppression depth is effectively a ratio. It is edifying to learn, as we show here, that suppression depth is constant as this indicates that whatever value the bCFS threshold has, the reCFS threshold will be *n* times lower. For example, a difference of -12 dB is a factor of four (e.g., bCFS = .2, reCFS = .05). It is important, though, to plot bCFS and reCFS values as well as suppression depth because these thresholds could be higher or lower for a different image category and yet still produce the same suppression depth (e.g., values of bCFS = .6 and reCFS = .15 also produce a suppression depth of -12 dB but are very different in absolute terms). Plotting bCFS and reCFS thresholds and suppression depth ensures absolute shifts are not obscured.

It is interesting to consider that the shapes of CRFs vary at different stages of cortical processing. CRFs tend to be shallower in V1 than in subsequent areas such as V2, V4 and FFA where they are considerably steeper. **Supplementary Figure 2** plots two CRFs, modelled with Naka-Rushton functions, showing a steep and a shallow version. The Naka-Rushton equation provides a very good description of the CRF (Albrecht & Hamilton, 1982) and is the preferred way to model them. The shallower CRF typifies that measured from neurons in primary visual cortex. It has a C50 (contrast giving half-max response) of 0.24 and an exponent of 3.4 – the mean values of a sample of 98 primate V1 CRFs reported by (Albrecht & Hamilton, 1982). The steeper CRF is typical of a V4 CRF and has a C50 of 0.15 and an exponent of 1.9 – the mean values of 131 V4 CRFs reported by (Cheng et al., 1994; Williford & Maunsell, 2006). For the sake of illustrating a key point, we have added horizontal lines labelled bCFS and reCFS threshold. We make the simple assumption that when contrast is ramping up, a target will break through from suppression to visibility when response level reaches the 'bCFS threshold'. Conversely, a visible target ramping down in contrast will become suppressed at the 'reCFS threshold'.



Supplementary Figure 1.

Perceptual durations in Experiments 1 to 3.

a) Average histogram across participants for all percept durations by experimental condition. Solid lines show tCFS conditions, broken lines show discrete (unidirectional) conditions. Shading corresponds to ±1 SEM corrected for within participant comparisons (Cousineau, 2005). **b-c)** Average histograms for tCFS in Experiment 2, and Experiment 3, respectively. Figure conventions as in a). **d)** tCFS durations of Experiment 3 when split by rate of contrast change. Vertical lines and arrows indicate the mean of median percept durations across participants.

		Slow RCC	Medium RCC	Fast RCC
Model	**Measure**			
(cubic) 1	R^2	.07	.19	.29
	BIC	-774.31	1343.79	-944.23
(harmonic) 2	R^2	.005	.006	0
	BIC	-706.85	1138.595	-600.34
(dHO) 3	R^2	.684	.632	.361
	BIC	-1847.19	-2125.29	-1041.29
Comparison				
2-1	ΔBIC	67.46	205.195	343.89
3-1	ΔBIC	-1072.88	-781.5	-97.06
3-2	ΔBIC	-1140.34	-986.695	-440.95

Supplementary Table 1.

Summary of results from model fits and comparisons.

The vertical lines in **Supplementary Figure 2** show the bCFS/reCFS threshold on the contrast axis, revealing a smaller range of 0.24 – 0.33 for the V1 CRF than for the V4 CRF (0.15 – 0.265). When expressed in decibels (SDdB = 20 * log10(reCFS/bCFS)) these thresholds produce suppression depths of 2.77 dB for the V1 CRF and 4.94 dB for the V4 CRF. This implies that CFS suppression should be deeper if it were occurring at the level of V4, and shallower if it were occurring in V1.

The suppression values calculated from the figure are smaller than those we report here in our data. However, it is important to note that the example CRFs in **Figure S2** are taken from recordings of single neurons, whereas an individual percept, such as a grating emerging into visibility, will be the result of a whole population of neurons. This is significant because when CRFs are derived from pooled neural responses using brain imaging techniques such as EEG or MEG population CRFs are much broader (Avidan et al., 2002; Hall et al., 2005). Importantly they broaden yet still maintain the same pattern as plotted in **Figure S2** where V1 CRFs show a more graded response to contrast and CRFs for areas beyond V1 show left-shifted and steeper CRFs. Therefore, the broader CRFs at the population level would produce much bigger bCFS/reCFS threshold differences and consequently a greater suppression depth that would be closer to the values we report here.

Outlining a realistic model of CRFs not only adds clarity about one of the key mechanisms underlying the contrast ramping procedure used in tCFS, it also allows us to make predictions and test hypotheses. For example: does CFS suppression depend on the type of target image? Neurons in area V4 are selective for polar form (Gallant et al., 1996) but V1 neurons are not. V1 neurons, on the other hand, are highly selective for linear gratings. Neither area is selective for faces, yet area FFA is specialised for this (Bao & Tsao, 2018) and shares similar CRFs to V4. If CFS suppression were to occur in the area specialised for a given target stimulus, our CRF model makes two predictions: (i) that the bCFS and reCFS thresholds should be very different when gratings are compared to polar gratings or faces (V1 bCFS/reCFS thresholds should be higher), and (ii) suppression depth should be greater for polar gratings and faces than for gratings. However, neither of these predictions is supported by our data. **Figure 3a** shows clearly that across different kinds of target images bCFS and reCFS thresholds tend to be very similar. Indeed, post hoc t-tests comparing gratings with objects, faces, and polar gratings show no significant differences between bCFS thresholds (all ps > .572) or reCFS thresholds (all ps > .285). Moreover, the level of suppression depth is the same (**Fig. 3b**). This pattern is not consistent with target images being suppressed in their preferred cortical areas but with suppression occurring in a single area governed by a common CRF. Based on our findings, we suggest the critical single area for CFS suppression is most likely area V1 because: (i) this is the first cortical area where interocular mismatches are detected, and (ii) regardless of image type, all target images tested in our study are very much mismatched with the Mondrian mask and would likely trigger interocular suppression at this first binocular stage. It remains a possibility that future work will uncover evidence of higher-level areas feeding into CFS suppression in a kind of hybrid model that has found support in studies of binocular rivalry suppression (van Boxtel et al., 2008; Wilson, 2003). One way to do that might be to create targets and masks that are congruent in as many features as possible to circumvent a front-end suppression triggered by an initial interocular mismatch.

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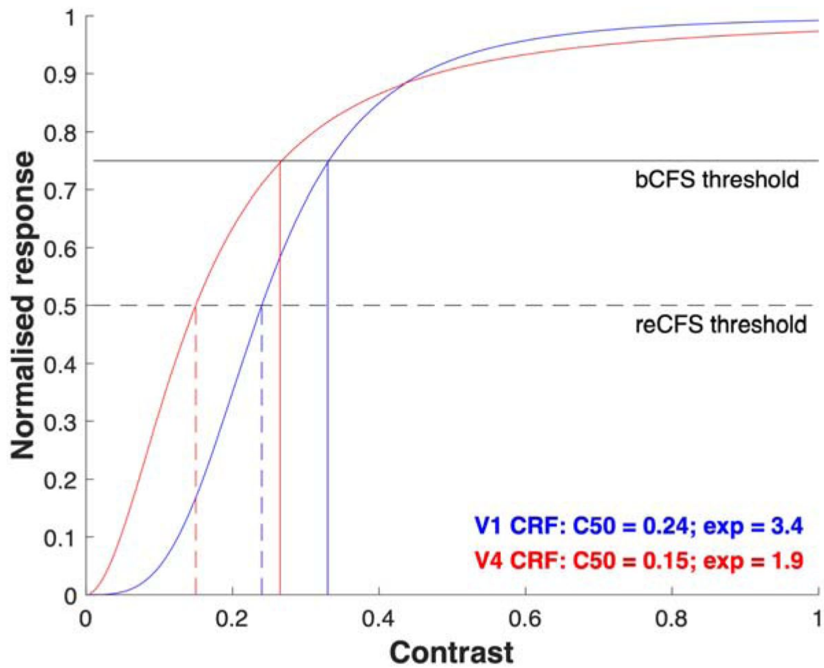

Supplementary Figure 2.

Contrast response functions and CFS thresholds.

Two Naka-Rushton functions modelling contrast response functions (CRFs) are shown, one has parameters typical of primary visual cortical neurons (blue) and the other is typical of CRFs found in area V4 (red). The C50 and exponent values are taken from single-unit neurophysiological studies of primate areas V1 and V4. We make the simple assumption that when contrast is ramping up, a target will break through from suppression to visibility when response level reaches the 'bCFS threshold'. Conversely, a visible target ramping down in contrast will become suppressed at the 'reCFS threshold'. Note that the V4 CRF has bCFS/reCFS thresholds that are much lower than those from the V1 CRF, and that the bCFS/reCFS range is greater for the V4 CRF, implying greater suppression depth (see appendix text). Our finding of constant suppression depth and very similar bCFS/reCFS thresholds across diverse image types suggests that CFS suppression for all our tested target images occurs in a common mechanism likely to be early in binocular processing.

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Reviewer #1 (Public Review):

Summary
A new method, tCFS, is introduced to offer richer and more efficient measurement of interocular suppression. It generates a new index, the suppression depth, based on the contrast difference between the up-ramped contrast for the target to breakthrough suppression and the down-ramped contrast for the target to disappear into suppression. A uniform suppression depth regardless of image types (e.g., faces, gratings and scrambles) was discovered in the paper, favoring an early-stage mechanism involving in CFS. Discussions about claims of unconscious processing and the related mechanisms.

Strength
The tCFS method adds to the existing bCFS paradigms by providing the (re-)suppression threshold and thereafter the depression depth. Benefiting from adaptive procedures with continuous trials, the tCFS is able to give fast and efficient measurements. It also provides a new opportunity to test theories and models about how information is processed outside visual awareness.

Weakness:
This paper reports the surprising finding of uniform suppression depth over a variety of stimuli. This is novel and interesting. But given the limited samples being tested, the claim of uniformity suppression depth needs to be further examined, with respect to different complexities and semantic meanings.
From an intuitive aspect, the results challenged previous views about "preferential

processing" for certain categories, though it invites further research to explore what exactly could suppression depth tell us about unconscious visual processing. The authors discussed about the possibility of gaining awareness according to different CRF functions in V1 and V4 neurons. But it confuses me about how the logic goes, especially from Line 713 to Line 718.

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Reviewer #2 (Public Review):

The following review for a revised manuscript is updated where appropriate and otherwise unchanged for completeness.

Summary
The paper concerns the phenomenon of continuous flash suppression (CFS), relevant to questions about the extent and nature of subconscious visual processing. Whereas standard CFS studies only measure the breakthrough threshold-the contrast at which an initially suppressed target stimulus with steadily increasing contrast becomes visible-the authors also measure the re-suppression threshold, the contrast at which a visible target with decreasing contrast becomes suppressed. Thus, the authors could calculate suppression depth, the ratio between the breakthrough and re-suppression thresholds. To measure both thresholds, the authors introduce the tracking-CFS method, a continuous-trial design that results in faster, better controlled, and lower-variance threshold estimates compared to the discrete trials standard in the literature. The study finds that suppression depths are similar for different image categories, providing an interesting contrast to previous results that breakthrough thresholds differ for different image categories. The new finding calls for a reassessment of interpretations based solely on the breakthrough threshold that subconscious visual processing is category-specific.

Strengths
(1) The tCFS method quickly estimates breakthrough and re-suppression thresholds using continuous trials, which also better control for slowly varying factors such as adaptation and attention. Indeed, tCFS produces estimates with lower across-subject variance than the standard discrete-trial method (Fig. 2). The tCFS method is straightforward to adopt in future research on CFS and binocular rivalry.

(2) The CFS literature has lacked re-suppression threshold measurements. By measuring both breakthrough and re-suppression thresholds, this work calculated suppression depth (i.e., the difference between the two thresholds), which warrants different interpretations from the breakthrough threshold alone.

(3) The work found that different image categories show similar suppression depths, suggesting some aspects of CFS are not category-specific. This result enriches previous findings that breakthrough thresholds vary with image categories. Re-suppression thresholds vary symmetrically, such that their differences are constant.

Weakness
The following concern remains from my initial review. Reviewer #3 raised a similar point in the last revision round, and I believe the authors do not fully address either comment. Thus, here I paraphrase my initial concern with reference to the authors' reply and discuss why it needs further elaboration.

I do not follow the authors' reasoning as to why the suppression depth is a better (or fuller, superior, more informative) indication of subconscious visual processing than the breakthrough threshold alone. To my previous round of comments, the authors replied that 'breakthrough provides only half of the needed information.' I do not understand this. One cannot infer the suppression depth from the breakthrough threshold alone, but *one cannot obtain the breakthrough threshold from the suppression depth alone*, either. The two measures are complementary. (To be sure, given *both* the suppression depth and the re-suppression threshold, one can trivially recover the breakthrough threshold. The discussion concerns the suppression depth *alone* and the breakthrough threshold *alone*.) I am fully open to being convinced that there is a good reason why the suppression depth may be more informative than the breakthrough threshold about a specific topic, e.g., inter-ocular suppression or subconscious visual processing. I only request that the authors make such an argument explicit. Preferably, this argument will precede claims that require it. For example, in the significance statement, the authors write, 'all images show equal suppression when both thresholds are measured. We *thus* find no evidence of differential unconscious processing and *conclude* reliance on breakthrough thresholds is misleading' (emphasis added). Just what supports the 'thus' and the 'conclude'? Similarly, at the end of the introduction, the authors write, '[...] suppression depth was constant for faces, objects, gratings and visual noise. *In other words*, we find no evidence to support differential unconscious processing among these particular, diverse categories of suppressed images' (emphasis added). I believe the statements before and after the period have not been shown to be equivalent. In the abstract, the authors revised, 'variations in bCFS thresholds alone are insufficient for inferring whether the barrier to achieving awareness exerted by interocular suppression is weaker for some categories of visual stimuli compared to others.' While I appreciate the added specificity, this claim still needs more support because the authors have not established that suppression depth is a better index than the breakthrough threshold of 'the barrier to achieving awareness exerted by interocular suppression.'

The authors' reply included a discussion of neural CRFs, which may explain why the bCFS thresholds differ across image categories. However, CRFs do not explain why the bCFS threshold does not implicate some component of subconscious processing. For example, the bCFS threshold may reflect the aspect of subconscious visual processing that corresponds to V1/V4 neural responses.

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Reviewer #3 (Public Review):

Summary:
In the 'bCFS' paradigm, a monocular target gradually increases in contrast until it breaks interocular suppression by a rich monocular suppressor in the other eye. The present authors extend the bCFS paradigm by allowing the target to reduce back down in contrast until it becomes suppressed again. The main variable of interest is the contrast difference between breaking suppression and (re) entering suppression. The authors find this difference to be constant across a range of target types, even ones that differ substantially in the contrast at which they break interocular suppression (the variable conventionally measured in bCFS). They also measure how the difference changes as a function of other manipulations. Interpretation is in terms of the processing of unconscious visual content, as well as in terms of the mechanism of interocular suppression.

Strengths:
Interpretation of bCFS findings is mired in controversy, and this is an ingenuous effort to move beyond the paradigm's exclusive focus on breaking suppression. The notion of using the contrast difference between breaking and entering suppression as an index of suppression depth is interesting.

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Author Response

The following is the authors' response to the original reviews.

> ***eLife assessment***
>
> *This valuable study introduces an innovative method for measuring interocular suppression depth, which implicates mechanisms underlying subconscious visual processing. The evidence supporting the effectiveness of this method would be solid after successfully addressing concerns raised by the reviewers. The novel method will be of interest not only to cognitive psychologists and neuroscientists who study sensation and perception but also to philosophers who work on theories of consciousness.*

Thank you for the recognition and appreciation of our work.

> ***Public Reviews:***
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> ***Reviewer #1 (Public Review):***
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> *Strengths:*
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> *The authors introduced a new adapted paradigm from continuous flash suppression (CFS). The new CFS tracking paradigm (tCFS) allowed them to measure suppression depth in addition to breakthrough thresholds. This innovative approach provides a more comprehensive understanding of the mechanisms underlying continuous flash suppression. The observed uniform suppression depth across target types (e.g., faces and gratings) is novel and has new implications for how the visual system works. The experimental manipulation of the target contrast change rate, as well as the modeling, provided strong support for an early interocular suppression mechanism. The authors argue that the breakthrough threshold alone is not sufficient to infer about unconscious processing.*
>
> *Weaknesses:*
>
> *A major finding in the current study is the null effect of the image categories on the suppression depth measured in the tCFS paradigm, from which the authors infer an early interocular mechanism underlying CFS suppression. This is not strictly logical as an inference based on the null effect. The authors may consider statistical evaluation of the null results, such as equivalence tests or Bayesian estimation.*

We have now included a Bayesian model comparison (implemented in JASP), to assess the strength of evidence in favour of the alternative hypothesis (or null effect). For example in Experiment 1 (comparing discrete to tCFS), we found inconsistent evidence in favour of the null effect of image-category on suppression depth:

Lines 382 – 388: "We quantified the evidence for this null-effect on suppression depth with a subsequent Bayesian model comparison. A Bayesian repeated-measures ANOVA (2 x 2; procedure x image type on suppression depth) found that the best model to explain suppression depth included the main effect of procedure (BF10 = 3231.74), and weak evidence/data insensitivity for image type (BF10 = 0.37). This indicates that the data was insensitive as to whether image-type was better at predicting suppression depth than the null model."

In Experiment 2, which was specifically designed to investigate the effect of image category on suppression depth, we found strong evidence in favour of the null:

Lines 429 – 431: “A Bayesian repeated-measures ANOVA (1 x 5, effect of image categories on suppression depth), confirmed strong evidence in favour of the null hypothesis (BF01 =20.30).

In Experiment 3, we also had image categories, but the effect of rate of contrast change was our main focus. For completeness, we have also included the Bayes factors for image-category in Experiment 3 in our text.

Lines 487- 490> “This null-effect of image-type was again confirmed with a Bayesian model comparison (3 speed x 4 image categories on suppression depth), demonstrating moderate support for the null effect of image category (BF01= 4.06).”

We have updated our Methods accordingly with a description of this procedure

Lines 297-305: “We performed Bayesian model comparison to quantify evidence for and against the null in JASP, using Bayesian repeated measures ANOVAs (uninformed prior with equal weight to all models). We report Bayes factors (B) for main effects of interest (e.g. effect of image type on suppression depth), as evidence in favour compared to the null model (BF10= B). Following the guidelines recommended in (Dienes 2021), B values greater than 3 indicate moderate evidence for H1 over H0, and B values less than 1/3 indicate moderate evidence in favour of the null. B values residing between 1/3 and 3 are interpreted as weak evidence, or an insensitivity of the data to distinguish between the null and alternative models.”

> *More importantly, since limited types of image categories have been tested, there may be some exceptional cases. According to "Twofold advantages of face processing with or without visual awareness" by Zhou et al. (2021), pareidolia faces (face-like non-face objects) are likely to be an exceptional case. They measured bidirectional binocular rivalry in a blocked design, similar to the discrete condition used in the current study. They reported that the face-like non-face object could enter visual awareness in a similar fashion to genuine faces but remain in awareness in a similar fashion to common non-face objects. We could infer from their results that: when compared to genuine faces, the pareidolia faces would have a similar breakthrough threshold but a higher suppression threshold; when compared to common objects, the pareidolia faces would have a similar suppression threshold but a low breakthrough threshold. In this case, the difference between these two thresholds for pareidolia faces would be larger than either for genuine faces or common objects. Thus, it would be important for the authors to discuss the boundary between the findings and the inferences.*

This is correct. We acknowledge that our sampling of image-categories is limited, and have added a treatment of this limitation in our discussion. We have expanded on the particular case of Zhou et al (2021), and the possibility of the asymmetries suggested:

Lines 669 – 691: “As a reminder, we explicitly tested image types that in other studies have shown differential susceptibility to CFS attributed to some form of expedited unconscious processing. Nevertheless, one could argue that our failure to obtain evidence for category specific suppression depth is based on the limited range of image categories sampled in this study. We agree it would be informative to broaden the range of image types tested using tCFS to include images varying in familiarity, congruence and affect. We can also foresee value in deploying tCFS to compare bCFS and reCFS thresholds for visual targets comprising physically meaningless ‘tokens’ whose global configurations can synthesise recognizable perceptual impressions. To give a few examples, dynamic configurations of small dots varying in location over time can create the compelling impression of rotational motion of a rigid, 3D object (structure from motion) or of a human engaged in given activity (biological motion) (Grossmann & Dobbins, 2006; Watson et al., 2004). These kinds of visual stimuli are associated with neural processing in higher-tier visual areas of the human brain, including the superior occipital lateral region (e.g., Vanduffel et al., 2002) and the posterior portion of the superior temporal sulcus (e.g., Grossman et al., 2000). These kinds of perceptually meaningful impressions of objects from rudimentary stimulus tokens are capable of engaging binocular rivalry. Such stimuli would be particularly useful in assessing high-level processing in CFS because they can be easily manipulated using phase-scrambling to remove the global percept without altering low-level stimulus properties. In a similar vein, small geometric shapes can be configured so as to resemble human or human-like faces, such as those used by (Zhou et al., 2021)[1]. These kinds of faux faces could be used in concert with tCFS to compare suppression depth with that associated with actual faces.

[1] Zhou et al. (2021) derived dominance and suppression durations with fixed-contrast images. In their study, genuine face images and faux faces remained suppressed for equivalent durations whereas genuine faces remained dominant significantly longer than did faux faces. The technique used by those investigators - interocular flash suppression (Wolfe, 1994) - is quite different from CFS in that it involves abrupt, asynchronous presentation of dissimilar stimuli to the two eyes. It would be informative to repeat their experiment using the tCFS procedure.

> ***Reviewer #2 (Public Review):***
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> *Summary*
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> *The paper introduces a valuable method, tCFS, for measuring suppression depth in continuous flash suppression (CFS) experiments. tCFS uses a continuous-trial design instead of the discrete trials standard in the literature, resulting in faster, better controlled, and lower-variance estimates. The authors measured suppression depth during CFS for the first time and found similar suppression depths for different image categories. This finding provides an interesting contrast to previous results that breakthrough thresholds differ for different image categories and refine inferences of subconscious processing based solely on breakthrough thresholds. However, the paper overreaches by claiming breakthrough thresholds are insufficient for drawing certain conclusions about subconscious processing.*

We agree that breakthrough thresholds can provide useful information to draw conclusions about unconscious processing – as our procedure is predicated on breakthrough thresholds. Our key point is that breakthrough provides only half of the needed information.

We have amended our manuscript thoroughly (detailed below) to accommodate this nuance and avoid this overreaching claim.

> *Strengths*
>
> *(1) The tCFS method, by using a continuous-trial design, quickly estimates breakthrough and re-suppression thresholds. Continuous trials better control for slowly varying factors such as adaptation and attention. Indeed, tCFS produces estimates with lower across-subject variance than the standard discrete-trial method (Fig. 2). The tCFS method is straightforward to adopt in future research on CFS and binocular rivalry.*
>
> *(2) The CFS literature has lacked re-suppression threshold measurements. By measuring both breakthrough and re-suppression thresholds, this work calculated suppression depth (i.e., the difference between the two thresholds), which warrants different interpretations from the breakthrough threshold alone.*
>
> *(3) The work found that different image categories show similar suppression depths, suggesting some aspects of CFS are not category-specific. This result enriches previous*

> *findings that breakthrough thresholds vary with image categories. Re-suppression thresholds vary symmetrically, such that their differences are constant.*

Thank you for this positive and succinct summary of our contribution. We have adopted your 3rd point "... suggesting that some aspects..." in our revised manuscript to more appropriately treat the ways that bCFS and reCFS thresholds may interact with suppression depths. For example:

Lines 850 – 852: "These [low level] factors could be parametrically varied to examine specifically whether they modulate bCFS thresholds alone, or whether they also cause a change in suppression depth by asymmetrically affecting reCFS thresholds".

> *Weaknesses*
>
> *(1) The results and arguments in the paper do not support the claim that 'variations in breakthrough thresholds alone are insufficient for inferring unconscious or preferential processing of given image categories,' to take one example phrasing from the abstract. The same leap in reasoning recurs on lines 28, 39, 125, 566, 666, 686, 759, etc.*

We have thoroughly updated our manuscript with respect to mentions of preferential processing, to avoid this leap in reasoning throughout. For example, this phrase in the abstract now reads:

Lines 27-30: "More fundamentally, it shows that variations in bCFS thresholds alone are insufficient for inferring whether the barrier to achieving awareness exerted by interocular suppression is weaker for some categories of visual stimuli compared to others".

> *Take, for example, the arguments on lines 81-83. Grant that images are inequivalent, and this explains different breakthrough times. This is still no argument against differential subconscious processing. Why are images non-equivalent? Whatever the answer, does it qualify as 'residual processing outside of awareness'? Even detecting salience requires some processing. The authors appear to argue otherwise on lines 694-696, for example, by invoking the concept of effective contrasts, but why is effective contrast incompatible with partial processing? Again, does detecting (effective) contrast not involve some processing? The phrases 'residual processing outside of awareness' and 'unconscious processing' are broad enough to encompass bottom-up salience and effective contrast. Salience and (effective) contrast are arguably uninteresting, but that is a different discussion. The authors contrast 'image categories' or semantics with 'low-level factors.' In my opinion, this is a clearer contrast worth emphasizing more. However, semantic processing is not equal to subconscious processing writ large.*

We are in agreement with your analysis that differential subconscious processing may contribute to differences between images, and have updated our manuscript to clarify this possibility. In particular, we have now included a section in our Discussion which offers a suggestion for future research, linking sensitivity to different low-level image features with differences in gain of the respective contrast-response functions.

From Lines 692 – 722: "Next we turn to another question raised about our conclusion concerning invariant depth of suppression: If certain image types have overall lower bCFS and reCFS contrast thresholds relative to other image types, does that imply that images in the former category enjoy "preferential processing" relative to those in the latter? Given the fixed suppression depth, what might determine the differences in bCFS and reCFS thresholds? Figure 3 shows that polar patterns tend to emerge from suppression at slightly lower contrasts than do gratings and that polar patterns, once dominant, tend to maintain dominance to lower contrasts than do gratings and this happens even though the rate of contrast change is identical for both types of stimuli. But while rate of contrast change is identical, the neural responses to those contrast changes may not be the same: neural responses to changing contrast will depend on the neural contrast response functions (CRFs) of the cells responding to each of those two types of stimuli, where the CRF defines the relationship between neural response and stimulus contrast. CRFs rise monotonically with contrast and typically exhibit a steeply rising initial response as stimulus contrast rises from low to moderate values, followed by a reduced growth rate for higher contrasts. CRFs can vary in how steeply they rise and at what contrast they achieve half-max response. CRFs for neurons in mid-level vision areas such as V4 and FFA (which respond well to polar stimuli and faces, respectively) are generally steeper and shifted towards lower contrasts than CRFs for neurons in primary visual cortex (which responds well to gratings). Therefore, the effective strength of the contrast changes in our tCFS procedure will depend on the shape and position of the underlying CRF, an idea we develop in more detail in Supplementary Appendix 1, comparing the case of V1 and V4 CRFs. Interestingly, the comparison of V1 and V4 CRFs shows two interesting points: (i) that V4 CRFs should produce much lower bCFS and reCFS thresholds than V1 CRFs, and (ii) that V4 CRFs should produce more suppression than V1 CRFs. Our data do not support either prediction: Figure 3 shows that bCFS and reCFS thresholds are very similar for all image categories and suppression depth is uniform. There is no room in these results to support the claim that certain images receive "preferential processing" or processing outside of awareness, although there are many other kinds of images still to be tested and exceptions may potentially be found. As a first step in exploring this idea, one could use standard psychophysical techniques (e.g., (Ling & Carrasco, 2006)) to derive CRFs for different categories of patterns and then measure suppression depth associated with those patterns using tCFS."

We have also expanded on this nuanced line of reasoning in a new Supplementary Appendix for the interested reader.

> *The preceding does not detract from the interest in finding uniform suppression depth. Suppression depth and absolute bCFS can conceivably be due to orthogonal mechanisms warranting their own interpretations. In fact, the authors briefly take this position in the Discussion (lines 696-704, 'A hybrid model ...'). The involvement of different mechanisms would defeat the argument on lines 668-670.*

We agree with this analysis, and note our response to Reviewer 1 and the possibility of exceptional cases that may affect absolute bCFS or reCFS thresholds independently.

Similarly, we agree with the notion that some aspects of CFS may not be category specific. The symmetric relationship of thresholds for a given category of stimuli should be assessed in the context of other categories, such as with pontillist images and by incorporating semantic features of images into the mask as in Che et al. (2019) and Han et al. (2021). This line of reasoning and suggestions for future research is provided in the revised discussion, beginning:

Lines 67: "Nevertheless, one could argue that our failure to obtain evidence for category specific suppression depth is based on a limited range of image categories…."

> *(2) These two hypotheses are confusing and should be more clearly distinguished: a) varying breakthrough times may be due to low-level factors (lines 76-79); b) uniform suppression depth may also arise from early visual mechanisms (e.g., lines 25-27).*

Thank you for highlighting this opportunity for clarification. We have updated our text:

Lines 25 – 27: "This uniform suppression depth points to a single mechanism of CFS suppression, one that likely occurs early in visual processing, because suppression depth was not modulated by target salience or complexity”

Lines 78 – 79: “Sceptics argue, however, that differences in breakthrough times can be attributed to low-level factors such as spatial frequency, orientation and contrast that vary between images”

> *Neutral remarks*
>
> *The depth between bCFS and reCFS depended on measurement details such as contrast change speed and continuous vs. discrete trials. With discrete trials, the two thresholds showed inverse relations (i.e., reCFS > bCFS) in some participants. The authors discuss possible reasons at some length (adaptation, attention, etc.). Still, a variable measure does not clearly indicate a uniform mechanism.*

We have ensured our revised manuscript makes no mention of a uniform mechanism, although we frequently mention our result of uniform suppression depth.

> ***Reviewer #3 (Public Review):***
>
> *Summary:*
>
> *In the 'bCFS' paradigm, a monocular target gradually increases in contrast until it breaks interocular suppression by a rich monocular suppressor in the other eye. The present authors extend the bCFS paradigm by allowing the target to reduce back down in contrast until it becomes suppressed again. The main variable of interest is the contrast difference between breaking suppression and (re) entering suppression. The authors find this difference to be constant across a range of target types, even ones that differ substantially in the contrast at which they break interocular suppression (the variable conventionally measured in bCFS). They also measure how the difference changes as a function of other manipulations. Interpretation in terms of the processing of unconscious visual content, as well as in terms of the mechanism of interocular suppression.*

Thank you for your positive assessment of our methodology.

> *Strengths:*
>
> *Interpretation of bCFS findings is mired in controversy, and this is an ingenuous effort to move beyond the paradigm's exclusive focus on breaking suppression. The notion of using the contrast difference between breaking and entering suppression as an index of suppression depth is interesting, but I also feel like it can be misleading at times, as detailed below.*
>
> *Weaknesses:*
>
> *Here's one doubt about the 'contrast difference' measure used by the authors. The authors seem confident that a simple subtraction is meaningful after the logarithmic transformation of contrast values, but doesn't this depend on exactly what shape the contrast-response function of the relevant neural process has? Does a logarithmic transformation linearize this function irrespective of, say, the level of processing or the aspect of processing that we're talking about?*
>
> *Given that stimuli differ in terms of the absolute levels at which they break (and re-enter) suppression, the linearity assumption needs to be well supported for the contrast difference measure to be comparable across stimuli.*

Our motivation to quantify suppression depth after log-transform to decibel scale was two-fold. First, we recognised that the traditional use of a linear contrast ramp in bCFS is at odds with the well-characterised profile of contrast discrimination thresholds which obey a power law (Legge, 1981) and the observations that neural contrast response functions show the same compressive non-linearity in many different cortical processing areas (e.g.: V1, V2, V3, V4, MT, MST, FST, TEO. See (Ekstrom et al., 2009)). Increasing contrast in linear steps could thus lead to a rapid saturation of the response function, which may account for the overshoot that has been reported in many canonical bCFS studies. For example, in (Jiang et al., 2007), target contrast reached 100% after 1 second, yet average suppression times for faces and inverted faces were 1.36 and 1.76 seconds respectively. As contrast response functions in visual neurons saturate at high contrast, the upper levels of a linear contrast ramp have less and less effect on the target's strength. This approach to response asymptote may have exaggerated small differences between stimulus conditions and may have inflated some previously reported differences. In sum, the use of a log-transformed contrast ramp allows finer increments in contrast to be explored before saturation, a simple manipulation which we hope will be adopted by our field.

Second, by quantifying suppression depth as a decibel change we enable the comparison of suppression depth between experiments and laboratories, which inevitably differ in presentation environments. As a comparison, a reaction-time for bCFS of 1.36 s can not easily be compared without access to near-identical stimulation and testing environments. In addition once ramp contrast is log transformed it effectively linearises the neural contrast response function. This means that comparing different studies that use different contrast levels for masker or target can be directly compared because a given suppression depth (for example, 15 dB) is the same proportionate difference between bCFS and reCFS regardless of the contrasts used in the particular study.

We also acknowledge that different stimulus categories may engage neural and visual processing associated with different contrast gain values (e.g., magno- vs parvo-mediated processing). But the breaks and returns to suppression of a given stimulus category would be dependent on the same contrast gain function appropriate for that stimulus which thus permits their direct comparison. Indeed, this is why our novel approach offers a promising technique for comparing suppression depth associated with various stimulus categories (a point mentioned above). Viewed in this way, differences in actual durations of break times (such as we report in our paper) may tell us more about differences in gain control within neural mechanisms responsible for processing of those categories.

We have now included a summary of these arguments in a new paragraph of our discussion (from lines 696- cf Reviewer 2 above), as well as a new Supplementary Appendix.

> *Here's a more conceptual doubt. The authors introduce their work by discussing ambiguities in the interpretation of bCFS findings with regard to preferential processing, unconscious processing, etc. A large part of the manuscript doesn't really interpret the present 'suppression depth' findings in those terms, but at the start of the discussion section (lines 560-567) the authors do draw fairly strong conclusions along those lines: they seem to argue that the constant 'suppression depth' value observed across different stimuli argues against preferential processing of any of the stimuli, let alone under suppression. I'm not sure I understand this reasoning. Consider the scenario that the visual system does preferentially process, say, emotional face images, and that it does so under suppression as well as outside of suppression. In that scenario, one might expect the contrast at which such a face breaks suppression to be low (because the face is preferentially processed under suppression) and one might also expect the contrast at which the face enters suppression to be low (because the face is preferentially processed outside of suppression). So the difference between the two contrasts might not stand out: it might be the same as for a stimulus that is not preferentially processed at all. In sum, even though the author's label of 'suppression depth' on the contrast difference measure*

> *is reasonable from some perspectives, it also seems to be misleading when it comes to what the difference measure can actually tell us that bCFS cannot.*

We have addressed this point with respect to the differences between suppression depth and overall value of contrast thresholds in our revised discussion (reproduced above), and supplementary appendix.

> *The authors acknowledge that non-zero reaction time inflates their 'suppression depth' measure, and acknowledge that this inflation is worse when contrast ramps more quickly. But they argue that these effects are too small to explain either the difference between breaking contrast and re-entering contrast to begin with, or the increase in this difference with the contrast ramping rate. I agree with the former: I have no doubt that stimuli break suppression (ramping up) at a higher contrast than the one at which they enter suppression (ramping down). But about the latter, I worry that the RT estimate of 200 ms may be on the low side. 200 ms may be reasonable for a prepared observer to give a speeded response to a clearly supra-threshold target, but that is not the type of task observers are performing here. One estimate of RT in a somewhat traditional perceptual bistability task is closer to 500 ms (Van Dam & Van Ee, Vis Res 45 2005), but I am uncertain what a good guess is here. Bottom line: can the effect of contrast ramping rate on 'suppression depth' be explained by RT if we use a longer but still reasonable estimated RT than 200 ms?*

A 500 ms reaction time estimate would not account for the magnitude of the changes observed in Experiment 3. Suppression depths in our slow, medium, and fast contrast ramps were 9.64 dB, 14.64 dB and 18.97 dB, respectively (produced by step sizes of .035, .07 and .105 dB per video frame at 60 fps). At each rate, assuming a 500 ms reaction time for both thresholds would capture a change of 2.1 dB, 4.2 dB, 6.3 dB. This difference cannot account for the size of the effects observed between our different ramp speeds. Note that any critique using the RT argument also applies to all other bCFS studies which inevitably will have inflated breakthrough points for the same reason.

We've updated our discussion with this more conservative estimate:

Lines 744 – 747: "For example, if we assume an average reaction time of 500 ms for appearance and disappearance events, then suppression depth will be inflated by ~4.2 dB at the rate of contrast change used in Experiments 1 and 2 (.07 dB per frame at 60 fps). This cannot account for suppression depth in its entirety, which was many times larger at approximately 14 dB across image categories."

Lines 755 – 760: [In Experiment 3] "Using the same assumptions of a 500 ms response time delay, this would predict a suppression depth of 2.1 dB, 4.2 dB and 6.3 dB for the slow, medium and fast ramp speeds respectively. However, this difference cannot account for the size of the effects (Slow 9.64 dB, Medium 14.6 dB, Fast 18.97 dB). The difference in suppression depth based on reaction-time delays (± 2.1 dB) also does not match with our empirical data (Medium - Slow = 4.96 dB; Fast - Medium = 4.37 dB)"

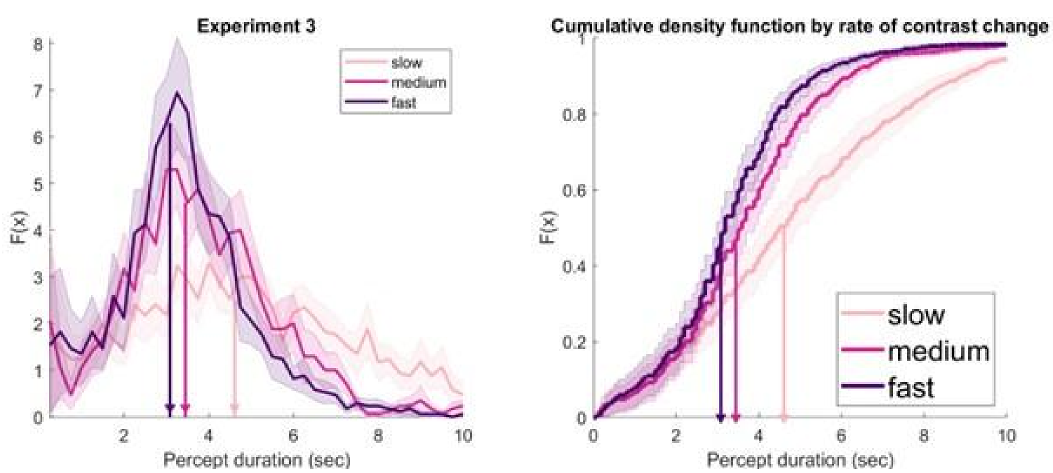
> *A second remark about the 'ramping rate' experiment: if we assume that perceptual switches occur with a certain non-zero probability per unit time (stochastically) at various contrasts along the ramp, then giving the percept more time to switch during the ramping process will lead to more switches happening at an earlier stage along the ramp. So: ramping contrast upward more slowly would lead to more switches at relatively low contrast, and ramping contrast downward more slowly would lead to more switches at relatively high contrasts. This assumption (that the probability of switching is non-zero at various contrasts along the ramp) seems entirely warranted. To what extent can that type of consideration explain the result of the 'ramping rate' experiment?*

We agree that for a given ramp speed there is a variable probability of a switch in perceptual state for both bCFS and reCFS portions of the trial. To put it in other words, for a given ramp speed and a given observer the distribution of durations at which transitions occur will exhibit variance. We see that variance in our data (just as it's present in conventional binocular rivalry duration histograms), as a non-zero probability of switches at very short durations (for example). One might surmise that slower ramp speeds would afford more opportunity for stochastic transitions to occur and that the measured suppression depths for slow ramps are underestimates of the suppression depth produced by contrast adaptation. Yet by the same token, the same underestimation would occur during fast ramp speeds, indicating that that difference may be even larger than we reported. In our revision we will spell this out in more detail, and indicate that a non-zero probability of switches at any time may lead to an underestimation of all recorded suppression depths.

In our data, we believe the contribution of these stochastic switches are minimal. Our current Supplementary Figure 1(d) indicates that there is a non-zero probability of responses early in each ramp (e.g. durations < 2 seconds), yet these are a small proportion of all percept durations. This small proportion is clear in the empirical cumulative density function of percept durations, which we include below. Notably, during slow-ramp conditions, average percept durations actually increased, implying a resistance to any effect of early stochastic switching.

Author response image 1.

The data from Supplementary FIgure 1D. (right) Same data reproduced as a cumulative density function. The non-zero probability of a switch occurring (for example at very short percept durations) is clear, but a small proportion of all switches. Notably, In slow ramp trials, there is more time for this stochastic switching to occur, which should underestimate the overall suppression depth. Yet during slow-ramp conditions, average percept durations increased (vertical arrows), implying a resistance to any effect of early stochastic switching.



> *When tying the 'dampened harmonic oscillator' finding to dynamic systems, one potential concern is that the authors are seeing the dampened oscillating pattern when plotting a very specific thing: the amount of contrast change that happened between two consecutive perceptual switches, in a procedure where contrast change direction reversed after each switch. The pattern is not observed, for instance, in a plot of neural activity over time, threshold settings over time, etcetera. I find it hard to assess what the observation of this pattern when representing a rather unique aspect of the data in such*

a specific way, has to do with prior observations of such patterns in plots with completely different axes.

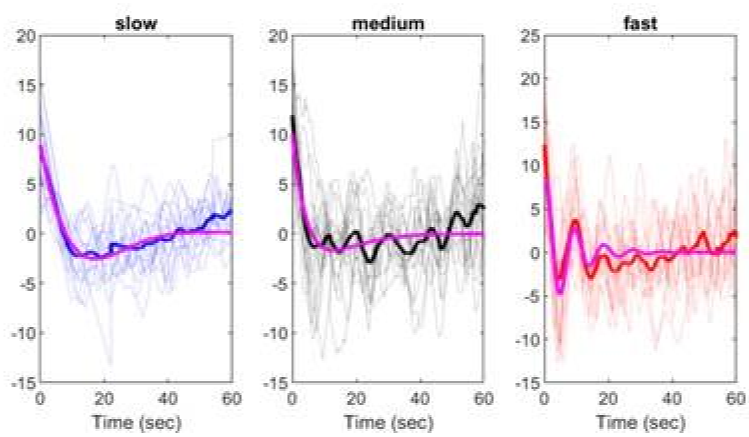
We acknowledge that fitting the DHO model to response order (rather than time) is a departure from previous investigations modelling oscillations over time. Our alignment to response order was a necessary step to avoid the smearing which occurs due to variation in individual participant threshold durations.

Our Supplementary Figure 1 shows the variation in participant durations for the three rates of contrast change. From this pattern we can expect that fitting the DHO to perceptual changes over time would result in the poorest fit for slow rates of change (with the largest variation in durations), and best fit for fast rates of change (with least variation in durations).

That is indeed what we see, reproduced in the review figure below. We include this to show the DHO is still applicable to perceptual changes over time when perceptual durations have relatively low variance (in the fast example), but not the alternate cases. Thus the DHO is not only produced by our alignment to response number - but this step is crucial to avoid the confound of temporal smearing when comparing between conditions.

Author response image 2.

DHO fit to perceptual thresholds over time. As a comparison to manuscript Figure 5 (aligning to response order), here we display the raw detrended changes in threshold over time per participant, and their average. Individual traces are shown in thin lines, the average is thick. Notably, in the slow and medium conditions, when perceptual durations had relatively high variance, the DHO is a poor fit to the average (shown in pink). The DHO is still an excellent fit in fast conditions, when modelling changes in threshold over time, owing to the reduced variance in perceptual durations (cf. Supplementary Figure 1). As a consequence, to remove the confound of individual participant durations, we have fitted the DHO when aligned to response order in our manuscript.



Recommendations for the authors:

Reviewer #1 (Recommendations For The Authors):

The terminology used: "suppression depth". The depth of interocular suppression indexed by detection threshold has long been used in the literature, such as in Tsuchiya et al., 2006. I notice that this manuscript has created a totally different manipulative definition of the depth of suppression, the authors should make this point clear to the readers to avoid confusion.

We believe that our procedure does not create a new definition for suppression depth, but rather utilises the standard definition used for many years in the binocular rivalry literature: the ratio between a threshold measured for a target while it is in the state of suppression and for that same target when in the dominance state.

We have now revised our introduction to make the explicit continuation from past methods to our present methodology clear:

Lines 94 – 105: "One method for measuring interocular suppression is to compare the threshold for change-detection in a target when it is monocularly suppressed and when it is dominant, an established strategy in binocular rivalry research (Alais, 2012; Alais et al., 2010; Alais & Melcher, 2007; Nguyen et al., 2003). Probe studies using contrast as the dependent variable for thresholds measured during dominance and during suppression can advantageously standardise suppression depth in units of contrast within the same stimulus (e.g., Alais & Melcher, 2007; Ling et al., 2010). Ideally, the change should be a temporally smoothed contrast increment to the rival image being measured (Alais, 2012), a tactic that preludes abrupt onset transients and, moreover, provides a natural complement to the linear contrast ramps that are standard in bCFS research. In this study, we measure bCFS thresholds as the analogue of change-detection during suppression, and as their complement, record thresholds for returns to suppression (reCFS)."

> *The paper provides a new method to measure CFS bidirectionally. Given the possible exceptional case of pareidolia faces, it would be important to discuss how the bidirectional measurement offers more information, e.g., how the bottom-up and top-down factors would be involved in the breakthrough phase and the re-suppression phase.*

In our discussion, we have now included the possibility of exceptional cases (such as pareidolia faces), and how an asymmetry may arise with respect to separate image categories affecting either bCFS or reCFS thresholds orthogonally.

Lines 688 - 691: "...In a similar vein, small geometric shapes can be configured so as to resemble human faces, such as those used by Zhou et al. (2021)[footnote]. These kinds of faux faces could be used in concert with tCFS to compare suppression depth with that associated with actual faces.

[footnote] Zhou et al. (2021) derived dominance and suppression durations with fixed-contrast images. In their study, genuine face images and faux faces remained suppressed for equivalent durations whereas genuine faces remained dominant significantly longer than did faux faces. The technique used by those investigators - interocular flash suppression (Wolfe, 1994) - is quite different from CFS in that it involves abrupt, asynchronous presentation of dissimilar stimuli to the two eyes. It would be informative to repeat their experiment using the tCFS procedure."

> *What makes the individual results in the discrete condition much less consistent than the tCFS (in Figure 2c)? The authors discussed that motivation or attention to the task would change between bCFS and reCFS blocks (Line 589). But this point is not clear. Does not the attention to task also fluctuate in the tCFS paradigm, as the target continuously comes and goes?*

We believe the discrete conditions have greater variance owing to the blocked design of the discrete conditions. A sequence of bCFS thresholds was collected in order (over ~15 mins), before switching to a sequence of back-to-back discrete reCFS thresholds (another ~15 mins), or a sequence of the tCFS condition. As the order of these blocks was randomized, thresholds collected in the discrete bCFS vs reCFS blocks could be separated by many minutes. In contrast, during tCFS, every bCFS threshold used to calculate the average is accompanied by a corresponding reCFS threshold collected within the same trial, separated by seconds. Thus the tCFS procedure naturally controls for waxing and waning attention, as within every change in attention, both thresholds are recorded for comparison.

A second advantage is that because the tCFS design changes contrast based on visibility, targets spend more time close to the threshold governing awareness. This reduced distance to thresholds remove the opportunity for other influences (such as oculomotor influences, blinks, etc), from introducing variance into the collected thresholds.

> *Experiment 3 reported greater suppression depth with faster contrast change. Because the participant's response was always delayed (e.g., they report after they become aware that the target has disappeared), is it possible that the measured breakthrough threshold gets lower, the re-suppression threshold gets higher, just because the measuring contrast is changing faster?*

We have included an extended discussion of the contribution of reaction-times to the differences in suppression depth we report. Importantly, even a conservative reaction time of 500 ms, for both bCFS and reCFS events, cannot account for the difference in suppression depth between conditions.

Lines 755 – 760> “Using the same assumptions of a 500 ms response time delay, this would predict a suppression depth of 2.1 dB, 4.2 dB and 6.3 dB for the slow, medium and fast ramp speeds respectively. However, this difference cannot account for the size of the effects (Slow 9.64 dB, Medium 14.6 dB, Fast 18.97 dB). The difference in suppression depth based on reaction-time delays (± 2.1 dB) also does not match with our empirical data (Medium - Slow = 4.96 dB; Fast - Medium = 4.37 dB).”

> *In the current manuscript, some symbols are not shown properly (lines 145, 148, 150, 303).*

Thank you for pointing this out, we will arrange with the editors to fix the typos.

> ***Reviewer #2 (Recommendations For The Authors):***
>
> *Line 13: 'time needed'-> contrast needed?*

This sentence was referring to previous experiments which predominantly focus on the time of breakthrough.

> *Line 57: Only this sentence uses saliency; everywhere else in the paper uses salience.*

We have updated to salience throughout.

> *Fig. 1c: The higher variance in discrete measurement results may be due to more variation in discrete trials, e.g., trial duration and inter-trial intervals (ITIs). Tighter control is indeed one advantage of the continuous tCFS design. For the discrete condition, it would help to report more information about variation across trials. How long and variable are the trials? The ITIs? This information is also relevant to the hypothesis about adaptation in Experiment 3.*

In the discrete condition, each trial ended after the collection of a single response. Thus the variability of the trials is the same as the variability of the contrast thresholds reported in Figure 2. The distribution of these ‘trials’ (aka percept durations), is also shown in Supplementary Figure 1.

The ITI between discrete trials was self-paced, and not recorded during the experiment.

> *Line 598: 'equivalently' is a strong word. The benefit is perhaps best stated relatively: bCFS and reCFS are measured under closer conditions (e.g., adaptation, attention) with continuous experiments compared to discrete ones.*

We agree - and have amended our manuscript:

Lines 629 – 632: “Alternating between bCFS/reCFS tasks also means that any adaptation occurring over the trial will occur in close proximity to each threshold, as will any waning of attention. The benefit being that bCFS and reCFS thresholds are measured under closer conditions in continuous trials, compared to discrete ones.”

> ***Reviewer #3 (Recommendations For The Authors):***
>
> *Figure 1 includes fairly elaborate hypothetical results and how they would be interpreted by the authors, but I didn't really see any mention of this content in the main text. It wasn't until I started reading the caption that I figured it out. A more elaborate reference to the figure would prevent readers from overlooking (part of) the figure's message.*

We have now made it clearer in the text that those details are contained in the caption to Figure 1.

Lines 113 – 115: “Figure 1 outlines hypothetical results that can be obtained when recording reCFS thresholds as a complement to bCFS thresholds in order to measure suppression depth.”

> *A piece of text seems to have been accidentally removed on line 267.*

Thank you, this has now been amended