Supporting Information

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SI Results and Discussion

Semantic Processing of Images Made Invisible by CFS. Although there is converging evidence that continuous flash suppression (CFS) diminishes bottom-up visual processing of the suppressed images (2–5), not all parts of the visual system are equally affected. Suppression seems to be much more pronounced within the ventral stream than the dorsal stream (5). This dissociation led to the prediction that although CFS seems to disrupt awareness regardless of stimulus type (but see below), manmade tools—hypothesized by some to rely more on dorsal stream processing—may receive semantic analysis even when conscious awareness is disrupted by CFS. In support of this prediction, Almedia et al. (6) found that images of tools suppressed through CFS can act as primes for a subsequent categorization response. However, this interpretation has been challenged by experiments showing that it is low-level visual properties (elongated shape) rather than semantic class that may be responsible for the tool vs. artifact dissociation (7).

One important exception concerns findings that emotional valence interacts with depth of suppression, such as emotionally arousing images breaking through suppression more quickly and how undetected erotic images can direct spatial attention. These effects are likely to be mediated via subcortical mechanisms (reviewed in ref. 8). There are also reports of depth of suppression being modulated by familiarity. For example, upright faces and familiar words emerge from suppression faster than inverted faces and words in a foreign script (9).

There are numerous reports of familiarity effects in visual representations. For example, familiarity modulates repetition suppression responses in anterior occipital–temporal cortex—a signature of processing efficiency (ref. 10 for discussion). It is unclear whether these effects are mediated by meaningfulness or familiarity (11), but it is conceivable that long-term exposure to certain classes of stimuli, such as faces and letters/words, leads to a recruitment of dedicated neural resources for efficient representation (12). As a consequence, familiar objects may require less signal to reach awareness, and one may therefore observe differences in suppression depth as a function of familiarity even in the absence of semantic processing. A familiarity advantage in processing efficiency also clarifies why some stimuli break through CFS faster, but suppressed objects still fail to prime processing of related stimuli (8).

Additional Experiments (Manipulation Check). In a powerful demonstration of continuous flash suppression (CFS) affecting low-level visual processing, Tsuchiya and Koch (1) showed that it reduces the strength of visual afterimages. To show that our CFS technique could likewise reduce visual afterimages, we performed two additional experiments that acted as manipulation checks (experiments 4a and 4b). Twenty undergraduates were recruited from University of Wisconsin-Madison for course credit. On each trial, participants viewed two identical visual adaptors (squares appeared black through the anaglyph glasses), positioned ~5° to the right or left of a central fixation. Observers were asked to maintain fixation on a central cross throughout. Experiments 4a and 4b ($n = 10$ each) differed only in the relative contrast of the adaptor square: low-contrast adaptor in experiment 4a, ensuring effective suppression, and higher-contrast adaptor in experiment 4b, used as a control (see below). On critical trials, one of the squares was masked using the CFS procedure in experiment 2. After 6 s, the display was replaced by a solid gray background, and participants judged which afterimage (left or right) appeared brighter.

If CFS reduced visual afterimages, participants should choose the side with the unsuppressed square more often than the suppressed square. On trials with only the unmasked adaptor visible, participants indicated that that side was brighter on 85% of the trials. When two adaptors of equal size and luminance were presented, participants chose the side with the unsuppressed adaptor 66% of the time, a reliable decrease, $F(1,9) = 5.45$, $P = 0.044$. This difference indicates that participants were not simply choosing, for example, the masked side. Critically, the unmasked adaptor was perceived to induce a brighter afterimage than the suppressed adaptor, as indicated by participants choosing the unsuppressed side reliably greater than chance, $t(9) = 3.09$, $P = 0.013$. When the adaptor contrast was increased, rendering CFS ineffective (experiment 4b), participants selected the unmasked side as brighter at a rate of 53%, not reliably greater than chance, $t < 1$. This result provides a basic proof-of-concept that the CFS procedure used in experiments 1 and 2 effectively alters basic visual processing.

Supplementary Analysis of Experiment 3 Detection Performance as a Function of Distribution of Orientations. The stimuli used in experiment 3 were generated by morphing from a square to a circle. This procedure generates a continuum that has psychologically validity such that stimuli become "better" circles as one moves along the continuum (Fig. 5). However, it is also possible to quantify the continuum using a purely objective physical measure of circularity that can then be correlated with detection performance. There is a variety of ways to compute "circularity." We chose to use Fourier component analysis (as implemented by the program Fiji; see ref. 13 for more details). As expected, the more circular the stimulus, the more uniform is the distribution of its orientations (Fig. S1). An effective "circle detector" would be tuned for a uniform orientation profile. As shown in Fig. S2*A*, variance of the distributions was, in fact, a highly reliable predictor of hit rates on trials on which participants heard the word "circle" ($r = -0.85$, $P = 0.001$). The distribution of orientations did not correlate with performance on no-cue trials, $r = -0.26$, $P > 0.4$.* Consequently, uniformity of variance predicted the "circle" advantage, that is, the difference between hit rates on the "circle" and no-cue trials, $r = -0.81$, $P = 0.002$ (Fig. S2*B*). A similar selective advantage of hearing "circle" is also observed when performance of "circle" trials is contrasted with "square" trials, $r = -0.73$, $P = 0.01$.

These results are consistent with the idea that hearing "circle" may provide a top-down signal to the visual system to facilitate processing of stimuli with a wide/uniform orientation profile.

A similar mechanism may be at work for more complex categories of the kind used in experiments 1 and 2. Hearing "rolling pin" may provide a top-down boost facilitating representations corresponding to long, conical objects (a mechanism not unlike tuning of spatial frequency described in refs. 15 and 16).

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*In an experiment not reported here, we found that when rectangular Mondrians were used as masks instead of curved line segments, the most square stimuli were strongly suppressed ($M_{hits} = 0.52$), whereas the circles were almost always detected ($M_{hits} = 0.90$). In this case, detection of shapes in the no-cue condition correlated was almost entirely predicted by the variance of orientation gradients, $r = -0.96$, $P < 0.0005$. A match in orientation profiles between masks and targets seems to be important for obtaining effective suppression (see also ref. 14).

It is less obvious what combination of features characterizes a birdhouse or doorknocker, especially considering the variety of forms these objects may take. These are important questions we leave for future research.

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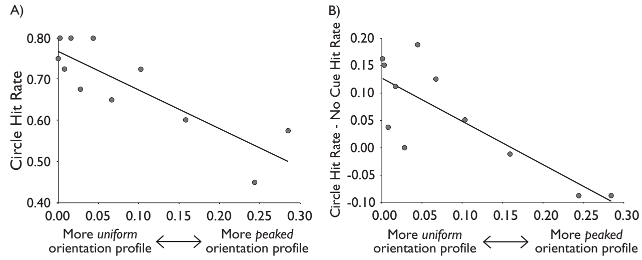

Fig. S1. Orientation profiles generated by a Fourier component analysis for the left-most and right-most stimuli used in experiment 3. (*A*) Profile of a square. (*B*) Profile of a circle.

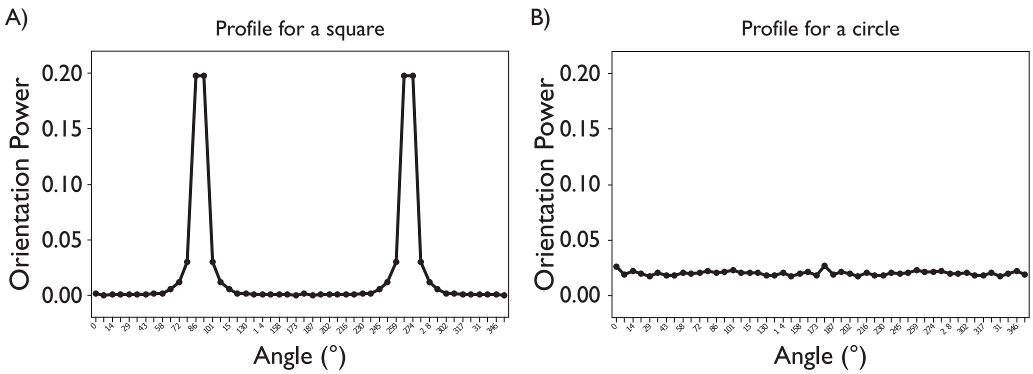

Fig. S2. Hit rates in experiment 3 as a function of gradient profile uniformity (variance $\times 10^2$). (*A*) Hit rates on detection trials followed by hearing "circle." (*B*) The advantage of hearing "circle" over a no-cue trial.

Table S1. Stimulus category listing for experiments 1 and 2

Experiment	Stimulus category
Experiment 1	Banana
	Football
	Kangaroo
	Pumpkin
	Rolling pin
	Swan
	Turtle
	Zebra
Experiment 2	Accordion
	Anchor
	Birdcage
	Birdhouse
	Cash register
	Coffeemaker
	Coffin
	Cooler
	Corkscrew
	Corset
	Crown
	Doorknocker
	Eyeglasses
	Feather
	Fireplace
	Highchair
	Houseplant
	Ice skates
	Kettle
	Laptop
	Laundry basket
	Leaf
	Mailbox
	Microphone
	Music stand
	Perfume bottle
	Pillow
	Robot
	Sewing machine
	Sink
	Soap dispenser
	Strainer
	Swiss army knife
	Toaster
	Tractor
	Tupperware container
	Typewriter
	Vacuum cleaner
	Wheelbarrow
	Wheelchair