Current Biology

Monocular Perceptual Deprivation from Interocular Suppression Temporarily Imbalances Ocular Dominance

Highlights

- Patching one eye temporarily boosts its subsequent dominance during binocular rivalry

- A comparable boost results from complete interocular suppression of an eye's image

- Viewing monocular images differing only in contrast also imbalances rivalry dominance

- Interocular suppression and eye patching implicate dynamic binocular gain control

Authors

Hyun-Woong Kim, Chai-Youn Kim, Randolph Blake

Correspondence

randolph.blake@vanderbilt.edu

In Brief

Patching an eye paradoxically strengthens its competitive advantage in binocular rivalry after patch removal. Kim et al. now show that this boost in strength can also be induced by interocular suppression that occurs when the two eyes view dissimilar monocular stimuli, implying short-term dynamic adjustments of ocular dominance.

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Monocular Perceptual Deprivation from Interocular Suppression Temporarily Imbalances Ocular Dominance

Hyun-Woong Kim,[1] Chai-Youn Kim,[1] and Randolph Blake[2,3,*]
[1]Department of Psychology, Korea University, Seoul 02842, Korea
[2]Vanderbilt Vision Research Center and Department of Psychology, Vanderbilt University, Nashville, TN 37240, USA
[3]Lead Contact
*Correspondence: randolph.blake@vanderbilt.edu
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SUMMARY

Early visual experience sculpts neural mechanisms that regulate the balance of influence exerted by the two eyes on cortical mechanisms underlying binocular vision [1, 2], and experience's impact on this neural balancing act continues into adulthood [3–5]. One recently described, compelling example of adult neural plasticity is the effect of patching one eye for a relatively short period of time: contrary to intuition, monocular visual deprivation actually *improves* the deprived eye's competitive advantage during a subsequent period of binocular rivalry [6–8], the robust form of visual competition prompted by dissimilar stimulation of the two eyes [9, 10]. Neural concomitants of this improvement in monocular dominance are reflected in measurements of brain responsiveness following eye patching [11, 12]. Here we report that patching an eye is unnecessary for producing this paradoxical deprivation effect: interocular suppression of an ordinarily visible stimulus being viewed by one eye is sufficient to produce shifts in subsequent predominance of that eye to an extent comparable to that produced by patching the eye. Moreover, this imbalance in eye dominance can also be induced by prior, extended viewing of two monocular images differing only in contrast. Regardless of how shifts in eye dominance are induced, the effect decays once the two eyes view stimuli equal in strength. These novel findings implicate the operation of interocular neural gain control that dynamically adjusts the relative balance of activity between the two eyes [13, 14].

RESULTS

Experiment 1

Seven observers participated in repeated testing sessions in which binocular rivalry dynamics were measured before and immediately after each of two different deprivation regimes. One regime involved wearing a translucent patch over one eye for 15 min, and the other entailed the use of continuous flash suppression (CFS), wherein one eye viewed a sinusoidal concentric grating (CG) while the other eye viewed a continuous stream of complex visual images that dominated visual awareness for long periods of time [15]. With CFS, therefore, it is possible to perceptually erase visual experience of a stimulus viewed by one eye without blocking patterned visual stimulation of that eye. Unlike the usual CFS sequence comprising Mondrian figures, our modified CFS sequence consisted of hundreds of colorful, unrelated images of outdoor scenes displayed sequentially at the rate of 10 frames/s (i.e., 10 Hz; see Figure 1A and Movie S1). Among those images was an occasional picture of a butterfly, the detection of which observers indicated by pressing a computer key; we included these infrequent images to encourage sustained attention to the CFS sequence. In a pilot experiment, we confirmed that this natural-scene CFS promotes prolonged interocular suppression as effectively as does a Mondrian-based CFS (Figure S1A). The rival stimuli used to assess relative predominance before and immediately after eye patch deprivation and before and immediately after CFS deprivation comprised a pair of orthogonally oriented gratings presented separately to the two eyes (Figure 1A).

Shown in Figure 1B are the first 12 successive dominance durations measured from two representative observers (one from each of the two labs involved in this project). Rival stimuli were presented to the deprived eye and the non-deprived eye during rivalry phases lasting 6 min immediately following a 15 min phase of monocular eye patching and, in a separate condition, following a 15 min phase of CFS. Figure 1C shows the normalized mean dominance durations averaged across all seven observers over the first 20 alternations of post-deprivation rivalry. For both patch deprivation and CFS deprivation, the dominance durations for the rival stimulus viewed by the deprived eye returned to and remained at pre-deprivation baseline levels within the early stage of post-deprivation rivalry, while the dominance durations for the rival stimulus viewed by the non-deprived eye (i.e., the unpatched eye during patch deprivation and the eye viewing the movie sequence during CFS deprivation) remained relatively briefer over a longer period of time.

For purposes of statistical analyses, we divided each observer's time-ordered normalized dominance durations into six quantiles for each session to calculate the mean durations for each of the six time-ordered sets of data. Then we averaged
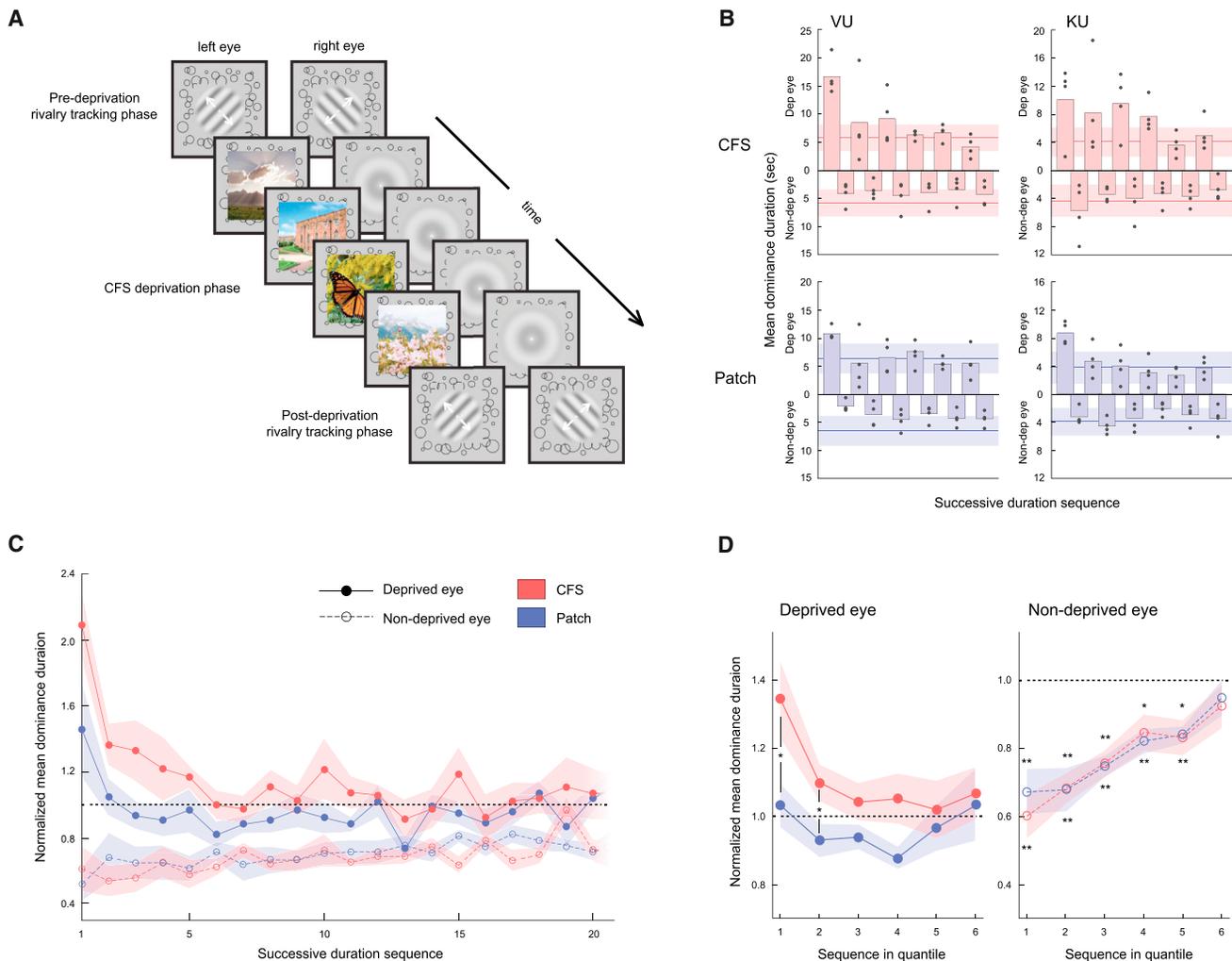
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Figure 1. Effects of Patch Deprivation and CFS Deprivation on Dominance Durations

(A) Schematic of task procedure with CFS deprivation. During the pre- and post-deprivation rivalry tracking phases, each of which lasted 6 min, binocular rivalry between dichoptically viewed, orthogonally oriented gratings was measured using a tracking procedure. During the intervening CFS deprivation phase, one eye viewed a CFS sequence composed of natural-scene images presented at a 10 Hz frame rate while the other eye viewed a sinusoidal CG pattern. Observers were instructed to press one key when a butterfly appeared within the image sequence and to press and hold another key during periods when the CG pattern achieved partial or complete visibility. See Supplemental Experimental Procedures for additional experimental details, and see Movie S1 for an example of the dichoptic display.

(B) Successive dominance durations for rival targets viewed by the deprived eye and by the non-deprived eye following CFS deprivation (upper panels) and following monocular eye patch deprivation (lower panels). "VU" and "KU" are two representative observers (one tested at Vanderbilt University and the other at Korea University). Dominance durations refer to the durations of exclusive visibility of a rival target, as indicated by the participants' key presses. Each bar denotes the mean dominance duration derived from four separate sessions, and each black dot indicates the actual dominance duration associated with each of those four sessions. Horizontal lines denote mean dominance durations for the respective eyes measured during rivalry tracking phases preceding deprivation (i.e., baseline levels), and the shaded region indicates the standard deviation of those mean values.

(C) Group-averaged successive normalized mean dominance durations for rival targets viewed by the deprived eye and by the non-deprived eye (n = 7). Normalized durations were computed by dividing each dominance duration by the mean dominance duration measured from rivalry tracking immediately preceding the deprivation phase for that session. Shaded regions indicate 1 SEM.

(D) Time-ordered quantile plots of normalized mean dominance durations for the deprived eye (left) and the non-deprived eye (right). For each observer's data, sequences of normalized dominance durations were divided into six quantiles for each session. For each quantile, we calculated mean dominance durations and averaged those over sessions. Then we computed group-averaged normalized mean dominance durations by averaging the individual quantile means over observers. Shaded regions indicate 1 SEM. *p < 0.05, **p < 0.01, FDR corrected.

those quantile means over the seven observers. As shown in the left panel of Figure 1D, CFS produced more robust increases in dominance durations of the grating viewed by the deprived eye than did eye patching, but this difference remained statistically

significant only into the second quantile (paired t tests, t(6) = 3.33, p < 0.05, false discovery rate [FDR] corrected for multiple comparisons). The deprivation effect in the non-deprived eye decayed slowly, remaining statistically significant into the fifth
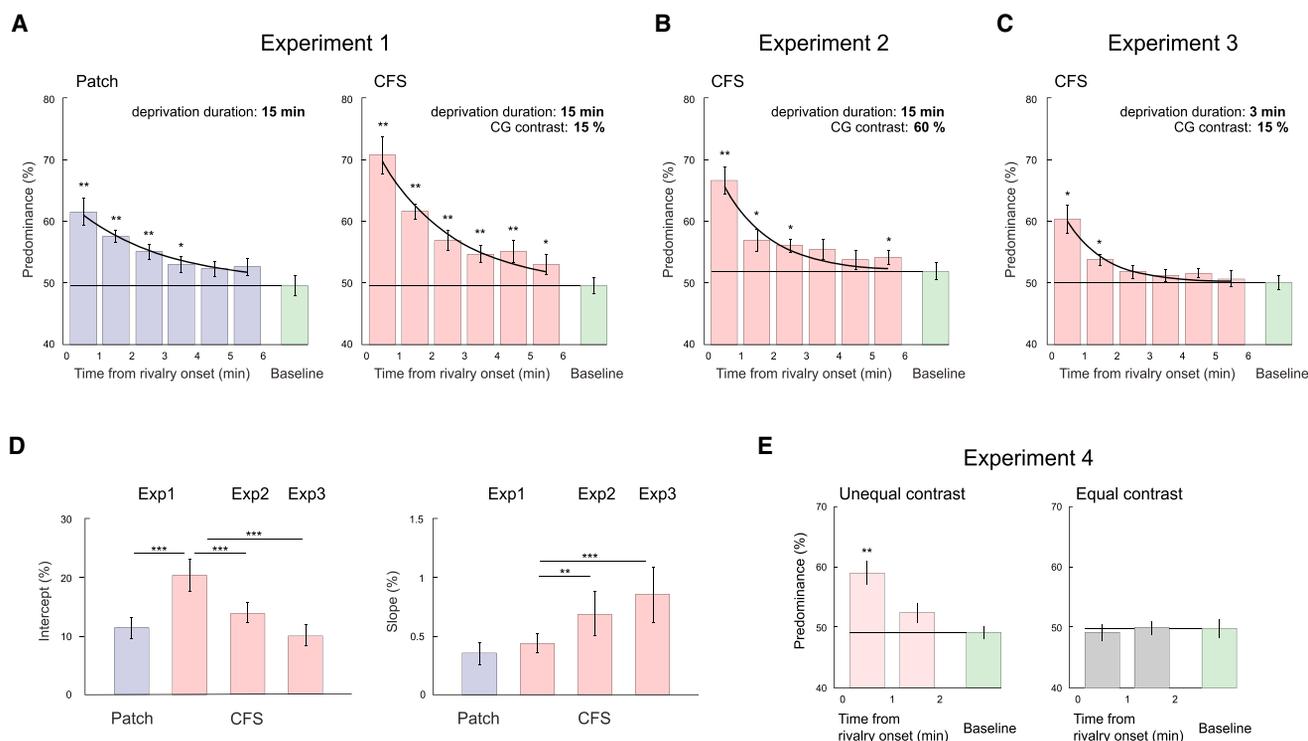
Figure 2. Effects of Deprivation on Predominance of the Deprived Eye

(A–C) Group-averaged predominance plots as a function of time elapsed from rivalry onset following (A) 15 min of monocular patch deprivation (left) or 15 min of CFS deprivation of a 15%-contrast CG pattern (right) (n = 7), (B) 15 min of CFS deprivation with 60%-contrast CG (n = 7), and (C) 3 min of CFS deprivation with 15%-contrast CG (n = 6). We divided each 6 min rivalry phase into six 1 min windows and calculated the predominance values of the deprived eye for each window. Predominance value within each 1 min window was defined as the total duration of the deprived eye being exclusively dominant divided by total duration except incomplete dominance durations (i.e., mixed dominance). Baseline was computed as the mean predominance of the to-be-deprived eye in the pre-deprivation rivalry periods. Black lines show the fitted functions with non-linear mixed-effects model. Error bars denote 1 SEM. *p < 0.05, **p < 0.01, FDR corrected. See also Figure S1 and S2.

(D) Intercept (left) and slope (right) parameter estimates of non-linear mixed-effects model fitted from predominance data following all four deprivation schemes. Error bars represent bootstrap standard errors. *p < 0.05, **p < 0.01, ***p < 0.001.

(E) Group-averaged predominance plots during the first and second minutes of rivalry following 3 min of exposure of the left eye and the right eye each to CFS natural-scene movies that were identical in spatial content (n = 9). In some sessions, the movies viewed by each eye were different in RMS contrast (unequal-contrast condition), and in other sessions they were identical in RMS contrast (equal-contrast condition). Baseline predominance was computed from rivalry tracking phases measured immediately before observers viewed the movies.

quantile both for CFS deprivation (one-sample t tests compared to 1, t(6) = 3.31, p < 0.05, FDR corrected) and for patch deprivation (t(6) = 6.30, p < 0.01, FDR corrected).

Consistent with the dominance duration results, the relative predominance of the grating viewed by the deprived eye was the greatest during the first minute of the 6 min post-deprivation rivalry phase, and predominance returned to the pre-deprivation baseline gradually over the remaining 5 min (Figure 2A). The biased predominance toward the grating viewed by the deprived eye remained significant for the entire 6 min after CFS deprivation (paired t tests compared to pre-deprivation baseline level of each observer, t(6) = 2.48, p < 0.05, FDR corrected) and for 4 min after patch deprivation (t(6) = 2.84, p < 0.05, FDR corrected).

To quantitatively express the recovery from ocular imbalance induced by patch deprivation and by CFS deprivation, the transient deprivation effects in predominance measured in experiment 1 were fitted with a non-linear mixed-effects model. We used an exponential function with two free parameters, including intercept indicative of initial amount of shift in predominance and slope indicative of decay rate. The asymptote parameter for baseline level was determined for each observer as the mean predominance during the pre-deprivation phase. The model exhibited good fits for both CFS and patch deprivation (solid black curve, Figure 2A), and this was true for all seven observers (Figure S2). We statistically compared the slope and intercept parameter estimates for patch and CFS deprivation using a bootstrap re-sampling analysis [16, 17], and those results are summarized in Figure 2D. The intercept parameter reflecting the initial shift in post-deprivation predominance in favor of the deprived eye was greater following CFS deprivation than it was following patching deprivation (bootstrap test, p < 0.001), but the slope parameter reflecting recovery rate was not significantly different for patch and CFS deprivation (bootstrap test, p = 0.33). Results from a hybrid condition involving patching combined with CFS stimulation (Figure S1B) suggest that the differential impact of CFS deprivation and patch deprivation in our experiment is attributable to the complexity of the stimulation

experienced by the non-deprived eye and by the sustained vigilance required to perform the detection task during CFS viewing [cf. 8].

Experiment 2

In experiment 1, the ordinarily visible CG pattern was rendered invisible for essentially the entire 15 min deprivation phase, owing to interocular suppression induced by the natural-scene CFS (total duration of pattern suppression averaged 98.1%, ranging from 96% to 100% among the seven observers). To learn whether increased visibility of the CG pattern would weaken the subsequent deprivation effect measured using rivalry, we repeated the CFS condition from experiment 1 using a much higher-contrast CG pattern (60%) to encourage its increased visibility during the CFS deprivation periods [18]. As expected, the CG achieved intermittent dominance more frequently, thus reducing its incidence of complete suppression to 69.5% (range: 53%–81%); the durations of CG dominance tended to be longer, too. Nonetheless, subsequent predominance of the rival grating viewed by the deprived eye was temporarily boosted during rivalry tracking following CFS deprivation (Figure 2B), albeit to a lesser extent and with a quicker decay than that measured following the same period of CFS deprivation during which the CG pattern was suppressed all of the time (Figure 2A). This conclusion emerges, too, from the statistical comparison of intercept (bootstrap test, p < 0.001) and slope (bootstrap test, p < 0.01) parameters of the non-linear mixed-effects model (solid black curve and histograms in Figure 2B, model parameters in Figure 2D).

Experiment 3

In a third experiment, we repeated the pre-test/CFS deprivation/post-test procedure using a 3 min CFS deprivation period, i.e., a duration considerably shorter than that used here and in earlier studies [6–8, 11, 12]. Remarkably, the bias in predominance toward the rival grating viewed by the deprived eye was significant for the initial 2 min of post-deprivation rivalry (t(5) = 4.93, p < 0.05, FDR corrected), confirming that a deprivation period as brief as 3 min is sufficient to produce a short-lived but reliable shift in predominance in favor of the deprived eye (Figure 2D). Not surprisingly, the model parameters for this condition reveal that the deprivation effect is weaker than that produced by 15 min of CFS deprivation (intercept: bootstrap test, p < 0.001) and that the decay of the deprivation effect is quicker (slope: bootstrap test, p < 0.001; Figure 2D). It remains to be learned whether very brief eye patching, too, shows this short-lived deprivation effect and whether the particular stimulus conditions experienced during the post-deprivation viewing period influence recovery. For now, it is gratifying to know that one need not employ prolonged deprivation periods to temporarily produce an imbalance of eye dominance in rivalry, for this may open the door to future studies of CFS-mediated shifts in ocular dominance using less-onerous durations of deprivation. For potential therapeutic purposes, such as treatment of amblyopia [19], however, patch deprivation is undoubtedly more practical.

Experiment 4

Both monocular eye patching and monocular CFS stimulation create conditions associated with binocular rivalry, i.e., dissimilar pattern stimulation to the two eyes. But is this a necessary condition for producing a temporary imbalance in eye predominance? To answer that question, we repeated the testing sequence used in experiment 3, except now the deprivation phase was replaced by 3 min of binocular presentation of the same CFS movie sequence to each eye, with both eyes viewing identical contrast sequences during some sessions (equal-contrast condition) and unequal contrast sequences during other sessions (unequal-contrast condition). For the latter condition, a given eye's root-mean-square (RMS) contrast was 20% of the other eye's RMS contrast; in the context of experiments 1–3, the eye receiving the lower contrast can be construed as "deprived." Before and immediately following viewing of those movie sequences, nine observers tracked rivalry between the orthogonally oriented gratings for 2 min.

Histograms in Figure 2E show group-averaged predominance values for the first and second minutes of rivalry tracking following the movie exposure for both contrast conditions. Contrast imbalance alone is sufficient to produce a reliable, robust deprivation effect during the first minute of post-movie rivalry dynamics (t(8) = 4.54, p < 0.01, FDR corrected). These results add weight to the conjecture that interocular contrast gain control provides an important component in the dynamic balancing process that is temporarily altered by monocular deprivation [6].

DISCUSSION

Our findings disclose that the seemingly paradoxical boost in eye dominance produced by extended monocular patching is not attributable to a total absence of patterned vision to the patched eye. Comparable changes in dominance can be achieved even when an eye receives patterned visual stimulation that is continuously blocked from visual awareness owing to interocular suppression produced by a potent form of CFS. Monocular eye patching, therefore, likely constitutes a form of continuous suppression induced by the extreme imbalance in stimulus strength experienced by the two eyes. Consistent with this interpretation, moderating the imbalance in stimulus strength during CFS deprivation by increasing the salience of the patterned visual stimulus attenuates the pronounced disparity in predominance immediately following deprivation by promoting occasional periods of visibility of that stimulus.

Could the deprivation effect generated by our stimulus conditions be an aftereffect of strong monocular adaptation of the eye viewing the CFS movie during the lengthy deprivation period, i.e., a temporary weakening of the effective contrast of the rival target imaged in that eye? Several reasons make us doubtful that this form of monocular adaptation provides the complete explanation. For one thing, the aftereffects of prolonged monocular pattern adaptation transfer robustly to the non-adapted eye [20], meaning that both eyes' rival patterns would be affected by neural adaptation to the CFS stimulus. For another thing, adaptation of the eye exposed to the potent CFS display would weaken the effective contrast of the rival target viewed by that eye following deprivation, relative to the target viewed by the deprived eye exposed to the low-contrast CG pattern. Research on binocular rivalry amply demonstrates that when the two eyes view rival targets differing in contrast, the stronger contrast target will be seen for longer durations, on average, compared to when

the contrasts are equal; this behavior is formalized as Levelt's second law [18]. But the post-deprivation rivalry durations from experiment 1 do not behave in a manner consistent with that law throughout the entire period of time during which that eye enjoys enhanced predominance. Compare the CFS deprivation curve in Figure 1C to that shown in Figure 2A—predominance remains biased in favor of the deprived eye for the entire 6 min, but individual dominance durations measured for the deprived eye return to baseline levels within a minute or so, contrary to the prediction based on Levelt's second law. To be sure, contrast adaptation may contribute to the initial spike in predominance of the deprived eye immediately following deprivation, but after that something more nuanced appears to be sustaining the predominance of the deprived eye. What might that be?

We favor the hypothesis advanced by Lunghi and colleagues [6] and subsequently supported by additional findings [21], namely that shifts in predominance produced by monocular deprivation arise from dynamic, experience-dependent changes in the balance of activation arising from left- and right-eye stimulation, i.e., binocular normalization, a form of homeostatic plasticity, as Lunghi and colleagues call it [19]. These mechanisms are very likely cortical in origin [11, 12, 22]. Binocular rivalry and its close relative CFS provide useful means for manipulating and gauging this balance of excitation and inhibition that govern binocular normalization [13, 14, 23]. Moreover, engagement of those mechanisms is not limited to rivalry conditions, for they also appear to operate when one views monocular stimuli matched in spatial content, as exemplified by the results from experiment 4. This means, in turn, that interocular suppression's impact on subsequently measured binocular rivalry dominance may have implications for understanding other documented changes associated with monocular patching, including improvement in stereoscopic resolution [24] and temporary boosts in a patched eye's subsequent contributions to dichoptic motion masking and to perceived binocular contrast and perceived binocular spatial phase [21].

EXPERIMENTAL PROCEDURES

Observers

Four female and three male observers (median age = 27; range: 19–70) participated in experiments 1 and 2. Six of them also participated in experiment 3. Nine observers (median age = 27; range: 23–70; five females, including five of the observers from experiments 1–3) participated in experiment 4. All experiments were performed at Korea University and at Vanderbilt University. All observers had normal or corrected-to-normal visual acuity and normal stereopsis. All gave written informed consent approved by the Institutional Review Boards of Korea University (1040548-KU-IRB-15-103-A-2(R-A-1)(E-A-1)) or Vanderbilt University (IRB #010110).

Experiment 1

Each test session comprised three phases: pre-deprivation rivalry, monocular deprivation, and post-deprivation rivalry. During pre- and post-deprivation rivalry phases, observers pressed one of two keys to signify which of the two orthogonally oriented gratings was currently dominant exclusively, with both keys being released during periods of mixed dominance. Pre- and post-deprivation rivalry phases lasted 6 min without a break.

During the intervening phase of monocular deprivation, observers were deprived of patterned vision through one eye for 15 min. This was accomplished in one of two ways during sessions: (1) patching: observers wore an opaque, translucent patch over one eye that blocked visible pattern information; while wearing the patch, observers were free to engage in normal activities (e.g., reading) within the confines of the laboratory; (2) CFS: visibility of

a monocularly viewed, moderately low-contrast (15%), sinusoidal CG was abolished by presentation of the CFS sequence to the other eye at the retinal location corresponding to the CG pattern viewed by the "deprived" eye. To minimize boredom during this 15 min phase of CFS, observers engaged in a vigilance task that entailed tapping a key whenever a butterfly appeared within the rapid sequence of CFS scene images. An image containing a butterfly was selected randomly from a small set of such images and inserted within the CFS sequence at unpredictable times. A brief auditory feedback tone signaled failures to respond within a 2 s interval following onset of a butterfly. Observers maintained excellent vigilance during the CFS sequence (90.4% of all butterflies were detected, with very few false alarms). Observers also reported any episodes of partial or complete visibility of the CG pattern by pressing and holding an additional key while the CG was visible. Following each deprivation phase was a 10 s interval during which the binocular fusion display alone was present, followed by the onset of the post-deprivation rivalry phase. Observers completed four sessions each for patch deprivation and for CFS deprivation, for a total of eight sessions presented in alternating order. Successive sessions were separated by at least 1 hour and, often, by as much as 1 day.

Experiments 2 and 3

Only CFS deprivation, not eye patching, was used during the four sessions comprising these two experiments. In experiment 2, the contrast of the CG pattern viewed during the 15 min CFS phase was 60%. In experiment 3, the duration of the CFS phase was shortened to 3 min, but otherwise stimuli and procedures were identical to those used in experiment 1.

Experiment 4

Stimuli and procedures were similar to those used in experiment 3, with a few exceptions. First, the duration of the two rivalry tracking phases was 2 min. Second, during the intervening 3 min period between rivalry phases, the two eyes dichoptically viewed CFS movie sequences that were identical in image content but not always identical in contrast. For the equal-contrast condition, left- and right-eye image frames were equal in RMS contrast (44%, averaged over images); for the unequal-contrast condition, the RMS contrast of each scene image viewed by one eye was reduced to 20% of that image's original RMS contrast, meaning that the RMS contrast of the CFS movie viewed by that eye was 8.8% on average. Third, there was only a 1 s break (except one observer, who was given a 3 s break) between the 3 min phase during which the movies were viewed and the subsequent 2 min phase of rivalry tracking. Observers completed four sessions for each of the two conditions in alternating order, with a minimum of 10 min of rest between sessions.

SUPPLEMENTAL INFORMATION

Supplemental Information includes Supplemental Experimental Procedures, two figures, and one movie and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2017.01.063.

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Adult Neuroplasticity: Working One Eye Gives an Advantage to the Other

Robert P. O'Shea[1,2]
[1]Discipline of Psychology, School of Psychology and Exercise Science, Murdoch University, Perth, Australia
[2]Discipline of Psychology, School of Health and Human Sciences, Southern Cross University, Coffs Harbour, Australia
Correspondence: r.oshea@murdoch.edu.au
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A recent study has found that viewing one image with one eye and a lower-contrast image with the other eye as briefly as a few minutes alters the subsequent balance of activity between the two eyes revealing adult neuroplasticity.

Between 1658–1675, Pierre Gassendi (1592–1655), philosopher, scientist, historian, and priest [1], considered an ancient question, first posed by Aristotle [2]: why, when we have two eyes, do we see only one visual world? Gassendi's answer, now known as *suppression theory*, is that we see with only one eye at a time:

> While the retina of one eye is concentrated, the retina of the other is relaxed, and so one acts while the other is idle … one of the eyes is always concentrated and shoulders the principal labor of vision, that is, it is concentrated on viewing something clearly, while the other in the meantime is at leisure and views only in a blurred manner and, in fact, perfunctorily and carelessly ([3] Physics lecture 3, book 7, chapter 7; from [4]).

We now know that Gassendi was wrong and that under normal circumstances we combine the information from the two eyes: *fusion theory*. For example, Wheatstone (1838) showed that information must be combined from the two eyes to yield precise information about the distance of objects from our eyes: binocular stereopsis [5]. We pay to experience this when we see a 3D movie. As they report in this issue of *Current Biology*, Kim et al. [6] have found that Gassendi was not completely wrong: making one eye work hard for a while does seem to exhaust it and to give an advantage to the other eye, although for different reasons from those Gassendi supposed. These discoveries have implications for adult neuroplasticity.

To test the relative activity of the two eyes, Kim et al. [6] used a phenomenon in which the two eyes seem to fight each other to give the images on their retinas to consciousness: *binocular rivalry* [5,7–9]. This is one circumstance in which suppression theory is correct. Gassendi must have known about binocular rivalry, because it was discovered about 80 years earlier [8]. Giambattista della Porta (1593), in an attempt to increase his productivity as a scientist, tried to read one book with one eye and another, simultaneously, with the other eye: he found he could read only one book at a time; the other book disappeared until he

switched his "visual virtue" [10] to the other book, at which point the first book disappeared.

Binocular rivalry has been the subject of numerous research papers [11], possibly because it offers a key to unlock the neural basis of visual consciousness. The rivalry display Kim et al. [6] used comprised a set of oblique lines tilted to the left viewed by one eye, and a similar set of oblique lines tilted to the right viewed by the other eye. For up to six minutes, the authors recorded the times the left-oblique lines and the right-oblique lines were visible without any trace of the other. When the lines were of equal contrast — that is, the difference between the light and dark parts of the lines was equal in the two eyes — those times were similar, showing that the left and right eyes were equally matched in the fight to give their contents to consciousness.

Having established a sensitive measure of the balance of activity between the eyes [12], Kim et al. [6] explored pre-conditions that would alter that balance. They began by patching one eye, something that had already been shown to affect subsequent rivalry [13]. The authors were able to show an effect on rivalry after 15 minutes of patching — 10 times briefer than from the previous research. The biasing of rivalry towards the previously patched eye persisted for 4 minutes — 27% of the patching time. In Gassendi's terms, the patched eye is taking an enforced rest while the open eye is shouldering the principal burden of vision. After the patch is removed, the image viewed by that eye enjoys an advantage in the fight for consciousness.

Kim et al. [6] then presented to one eye a low-contrast bull's-eye pattern, and to the other a continuous stream of different, high-contrast images that changed 10 times a second. Fifteen minutes of this display conferred an advantage in rivalry for the eye that had previously viewed the low-contrast image that lasted for 6 minutes — 40% of the pre-conditioning time. When they reduced the time of the conditioning display to 3 minutes, they found an effect on subsequent rivalry for 2 minutes — 67%. In Gassendi's terms, reducing the contrast viewed by one eye also allowed it to take a rest compared

to the other eye that was viewing the rapidly changing display of high-contrast images.

To determine if it is the contrast difference or the difference in the busyness of displays viewed by the two eyes, in their final experiment, Kim et al. [6] presented identical continuous streams of different, high-contrast images to both eyes for 3 minutes, except that one had lower contrast than the other. They found that subsequent rivalry was biased towards the eye viewing the lower contrast image stream for 1 minute — 33%. This showed that it was the lower contrast that allowed an eye to rest, not the busyness of the display.

The previous research using patching has been hailed as a breakthrough in adult neuroplasticity. Indeed, a similar display to Kim et al.'s [6] final experiment, but involving playing a video game for 40 hours with reduced contrast to the good eye of adults compared to their 'lazy eyes' (amblyopic eyes) has been found to improve vision from the lazy eye [14]. For a long time, such lazy eyes were considered untreatable in adults.

Although Gassendi's theory accounts for all of the findings of Kim et al. [6], they explained their results as a shift in the contrast gain of input to the binocular visual system [15,16]. This, I must say, is much more likely to be correct than Gassendi's theory. It is not correct to think of the two eyes as independent entities: they are fundamentally bound together into binocular vision. Closing an eye, or patching it, or giving it a lower-contrast image, does not make the visual system structurally monocular — it changes the weighting of the inputs from the two eyes into binocular vision. What Kim et al. [6] have shown is that this adjustment of the weighting of the two eyes happens quickly enough to have enduring effects on binocular vision once the patch is removed or the eye is opened or equality of contrast is restored. It's even possible that such changes represent the action of an evolved mechanism to compensate for changes in the focusing of that eye (which do lead to contrast changes to the image on that eye's retina), to

damage to that eye, or even to loss of that eye.

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