i-PERCEPTION

a Pion publication

*i-Perception* (2012) volume 3, pages 499–502

dx.doi.org/10.1068/i0547sas ISSN 2041-6695 perceptionweb.com/i-perception

***SHORT AND SWEET***

# Afterimages from unseen stimuli

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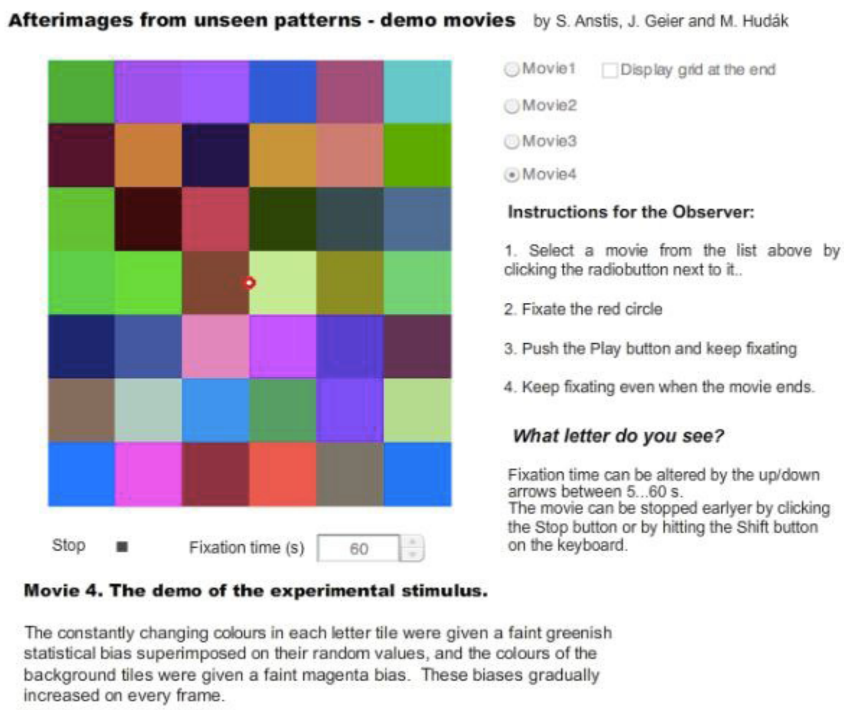
Received 30 June 2012, in revised form 13 July 2012; published 31 July 2012.

**Abstract.** Observers adapted to a field of randomly coloured twinkling tiles, in which was embedded a faint, subthreshold green letter. Observers failed to discern this letter, but they readily reported its pink afterimage afterwards. This demonstrates a storage of changing colours over time; adaptation occurs for the average of each retinal point.

**Keywords:** afterimage, color vision, visual storage, subthreshold summation.

An afterimage is usually weaker than the stimulus that induces it, as well as being of opposite colour. But here we show that an invisible stimulus can give a visible afterimage. The inducer was a faint, subthreshold green letter, masked by twinkling colour noise, and its afterimage was a strong, pink perceived letter. All four movies are embodied in this Flash file:




**Movies 1–4.** Please click image to play. Then use play button to start and stop.

The phenomenon is demonstrated in Movie1. To experience the illusion, just start the movie. (All movies are best viewed in a darkened room. If you do not see an afterimage on your first try, please increase the fixation time.) You will see coloured, flickering tiles. Fixate the centre for approximately 30 s. When the flickering stops, a homogeneous white background is presented. Most observers do not perceive any letter during the twinkling adapting phase, but afterwards they do see the pink afterimage of a capital letter. This letter is named at the end of the paper. The afterimages often take a few seconds to bloom gradually into view.

Movie1 was made with a $6 \times 7$ array of coloured square tiles, each subtending 1° angle. The R, G and B channels of each tile were randomly assigned a value of either 0 or 255, independently of each other. The frames of the display were refreshed at 10 Hz, producing coarsely pixelated dynamic random-dot noise. A letter was hidden in the centre of the display as follows: the probability that the R and B channels of the letter tiles were assigned the value of 255 was 25%, whereas on the G channel, the probability of 255 was 75%; and the probabilities for the background tiles were the opposite. This biased the probabilities in the letter tiles towards green, and, in the background tiles towards magenta. Therefore, the letter was not visible during the display, since physically no letter was presented in any of the frames. However, if all frames were averaged together, then there would be a green letter on a magenta background.

Did you have experience the magenta afterimage of a letter on a greenish background after watching the movie? This result is the same as if you had fixated a green letter on a magenta background. Therefore, it seems that you have adapted to the average of the frames while not seeing any letter in the meantime.

Black outlines are believed to facilitate the perception of any afterimages (Anstis, Van Lier, & Vergeer, manuscript submitted for publication; Daw, 1962; Hamburger, Geremek, & Spillmann, 2012; Van Lier, Vergeer, & Anstis, 2009; Van Boxtel & Koch, 2010). By checking this option in the Movies, you can test whether the grid-like outline at the end of the movie helps you detect the letter.

The effect also works in a black-and-white version (Movie 2). In this movie, the probability of 255 (white) in the letter tiles is 75%, but only 25% in the background tiles. Moreover, a black-and-white after-effect can be elicited even by a chromatic flickering stimulus (Movie 3). Guess, how.

As for the chromatic version of the afterimage, the same result can also be obtained by a different algorithm, which can be experienced in Movie 4. It was prepared as follows: in an array of $6 \times 7$ tiles, a letter-shaped subset of tiles was designated to spell a single capital letter. Each tile flickered at 10 Hz in independent, random colours, which were refreshed with new colours on every frame. The constantly changing colours in each letter tile were given a faint greenish statistical bias superimposed on their random values, and the colours of the background tiles were given a faint magenta bias. These biases gradually increased on every frame, in accordance with the following algorithm.

Let $y$ = yes, $n$ = no, and $f$ = frame number, $y = 1 + f \times 0.005$, and $n = 1/y$. Note that $n < 1 < y$. R, G and B began as randomly chosen integers from a universal distribution between 0 and 255 and were independent for every tile and every frame. The letter tiles were reset on every frame to $R \times n$, $G \times y$, $B \times n$ (biased towards green) and the background tiles were set to $R \times y$, $G \times n$, $B \times y$ (biased towards magenta). Hereby, the average of both the letter and the background tiles was 127 at the beginning, but the letter tiles gradually shifted towards green, and the background tiles towards magenta. By means of the low slope value (0.005), we ensured that the letter always remained below perceptual threshold. Adapting to Movie 4 for 20 s should suffice to give the pink afterimage of a letter. Watch Movie 4 for 60 s if you wish to see the colour bias gradually becoming visible.

We showed Movie 4 to 132 student participants. Following 45 s of adaptation to the twinkling random coloured tiles shown in Movie 4, with strict fixation on a central point, the display was switched to a congruent $6 \times 7$ test array of white tiles outlined in black, which was intended to facilitate the perception of the afterimage.

Participants viewed the stimulus from a great variety of distances and angles. Each student held a Clicker, which is a device like a TV remote, with five buttons labelled A through E. Students were told: 'You may see a shadowy letter, A, B, C, D or E, either during the flickering or the white phase of the stimulus. If you do, or think you do, please press the corresponding button on your clicker. If in doubt, feel free to guess.' All button pushes were detected and recorded by a central receiver at the front of the lecture hall, from which they were recorded for later analysis.

During the flickering adapting phase, 11 (8.3%) of the observers correctly reported a camouflaged letter (an 'E'). During the white test phase, 79 (59.8%) correctly identified the pink afterimage of the letter. Thus, observers were seven times as likely to identify the letter from its afterimage as from the original adapting stimulus.

Although most observers did not perceive these biases during the adaptation, they clearly saw their resulting afterimages. Thus, during adaptation, the target letters had a different mean colour from the background, but the deliberately high variance kept the signal/noise ratio of the bias below the observer's visual threshold—its d-prime was too low. Detecting the letter target in the twinkling display would require the visual system to act as a statistician, isolating the difference in the means while hindered by the variance. The afterimage, however, emerges from the sum and discards the variance. Nearly all observers saw the afterimage without ever discriminating the twinkling target that caused it and this shows that the formation of afterimages has a longer integrating time than perception does. Thus, the visual system stores and averages the stimulus colours over time.

Incidentally, the afterimage letters in Movies 1–4 were, respectively, H, E, L, P.

**Acknowledgments.** M.H. was supported by grant TÁMOP 4.2.1/B-09/1/KMR-2010–0002 and S.A. by a grant from the Department of Psychology, UC San Diego. The authors thank Sean Deering, Neal Dykman, Doreen Hsu, Katherine Hsueh, and Esther Strom for their assistance; and Beth Norman for granting access to her class of 132 students with clickers.

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**Stuart Anstis** took his Ph.D. in experimental psychology at the University of Cambridge under Richard Gregory. He then taught at the University of Bristol, then at York University in Toronto, Canada. For the last 20 years he has taught at UC San Diego. For more information visit http://psy2.ucsd.edu/~sanstis/Stuart_Anstis/Welcome.html.

**János Geier** (1950- ) mathematician, independent visual researcher. He took his MA in mathematics at Eötvös Loránd University, Budapest, after which he taught mathematics and statistics to students of psychology for 25 years there. He has dealt with visual science from the early 1990s; he visited Julesz Béla's laboratory and ARVO conferences numerous times. For the past 8 years, he has earned his bread from "teaching" the computer to recognize letters, within his private enterprise. His main interest is investigating the regularities of visual illusions, and modelling them mathematically-computationally. He considers mathematical models, which are general in theoretical physics, important in visual science, too.

**Mariann Hudák** (1983- ) took her MA in psychology and English at Eötvös Loránd University, Budapest, where she got involved into János Geier's work on the Hermann grid and other brightness illusions. She investigates the regularities of these "errors" by means of psychophysical experiments, which aim to provide new ideas to develop a unified theoretical model for all known low-level brightness phenomena, including contrast and assimilation illusions. From 2009 on, she has been taking her PhD under Ilona Kovács at the Budapest University of Technology and Economics, investigating developmental issues of vision, adaptation and binocular rivalry, besides continuing the work on lightness-brightness perception.



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