Short and Sweet

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The Joy of Retinal Painting: A Build-It-Yourself Device for Intrasaccadic Presentations

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Abstract
As the eyes move, they incessantly impose motion blur on the retinal image, yet our perception of the world remains undisturbed. In fact, it is often assumed that intrasaccadic visual signals are largely eliminated from processing by a dedicated suppression mechanism. Here, we describe an easy-to-build presentation device that produces a stimulus that is highly salient and well resolvable during saccades: Using LED strips with high temporal resolution, any type of text and image stimulus can be presented in an anorthoscopic fashion—as if seen through and travelling behind a narrow slit—at very short durations. Whereas these stimuli appear as a brief flash during fixation, saccades spread them across the retina, producing spatially extended and well-resolved retinal images. In fact, retinally painted images induced by saccades across a series of anorthoscopic image presentations were correctly identified by observers in 90% of all cases. So why should we suppress intrasaccadic perception if it enables us to experience the joy of retinal painting?

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A large body of literature in the field of active vision suggests that vision is suppressed around and during rapid eye movements, the so-called *saccades* (e.g., Castet, 2009; Volkmann, 1976). Indeed, unless saccades are made in a dark room with only a few small light sources present, human observers rarely perceive the massive amount of motion blur (also known as intrasaccadic smear) that saccades should induce as they sweep the whole visual scene across their retinae at dazzling velocities. The fact that the retinal consequences of our own saccades are omitted from visual perception is often thought to be realized by an active, extraretinal suppression mechanism—commonly known as saccadic suppression—that eliminates certain types of intrasaccadic visual input from further processing (Burr, Morrone, & Ross, 1994; Ross, Morrone, Goldberg, & Burr, 2001; Thiele, Henning, Kubischik, & Hoffmann, 2002). As a consequence, approximately one eighth of the visual information received while actively exploring the visual world should be discarded. This amounts to 2 hours on a day with a decent amount of sleep. Would it not be great to be able to utilize this significant amount of time? Here, we present a simple device that produces a salient, highly resolvable intrasaccadic stimulus by applying the principle of retinal painting. But before we get to this point, we must introduce two important facts.

First, visual processing is not shut down during saccades. For example, in a unique setup, Campbell and Wurtz (1978) showed that when a room was illuminated just during a saccade, so that the brief intrasaccadic scene was not masked by pre- and postsaccadic retinal images (Castet, Jeanjean, & Masson, 2002; Duyck, Collins, & Wexler, 2016; Matin, Clymer, & Matin, 1972), observers readily perceived a smeared and greyed-out scene. When they further reduced the duration of illumination to 5 ms or less, observers even reported a relatively clear image of the room (Campbell & Wurtz, 1978). The authors concluded that the effect of saccadic suppression—that is, the elevation of perisaccadic contrast thresholds by around 0.5 log units (Volkmann, 1986)—does not prevent intrasaccadic perception.

Second, to match the high velocities and brief durations of saccades, one would need costly stimulus presentation devices capable of high temporal resolution, as well as gaze-contingent control (e.g., Balsdon, Schweitzer, Watson, & Rolfs, 2018). Here, we utilize a different method, almost tailored for intrasaccadic purposes: *anorthoscopic presentation*. Anorthoscopic presentation is based on displaying small parts of visual objects in a sequential manner, one section at a time, as if seen through a narrow slit. The finding that observers were capable of anorthoscopic perception, that is, resolving the form and identity of figures from this kind of piecewise presentation despite the fact that the stimulus only covered a tiny part of the retina, has already fascinated researchers in the 19th century. To explain the phenomenon, Helmholtz (1867) proposed a retinal painting hypothesis that is quite relevant for our application: He suggested that (unconscious) eye movements across the slit might spread those sequential stimulations across the retina, thereby allowing visual persistence to create a spatially distinct pattern (Rock, 1981; Rock, Halper, DiVita, & Wheeler, 1987). Although this explanation does not hold for the more general phenomenon of anorthoscopic perception (Anstis & Atkinson, 1967; Fendrich, Rieger, & Heinze, 2005;

Rieger, Grüschow, Heinze, & Fendrich, 2007; Rock & Halper, 1969), it certainly is valid for the intrasaccadic case, where presentations are extremely brief and high eye velocities induce a considerable amount of spread across the retina.

Although anorthoscopes were traditionally built using two axially mounted disks—one showing the stimulus and the other moving the slit—we applied four Adafruit DotStar LED strips (Adafruit Industries, New York City, NY, USA) for presentation (see Figure 1 for schematic). Each had a length of 1 m and featured 144 5×5 mm RGB pixels that were controlled by a Raspberry Pi 3B (Raspberry Pi Foundation, Cambridge, UK) using the supplied DotStar Pi Painter Libraries (Burgess, 2015). In this LED-based anorthoscopic presentation, any kind of picture stimulus can be presented: After being rescaled to a vertical resolution corresponding to the number of LED pixels, the image is presented column-wise from left to right. During visual fixation, this kind of presentation will look like a brief flash (Figure 2, left). If the same presentation happens to occur during a saccade, the presented columns will fall on different parts of the retina, creating a spatially distributed pattern, easily perceivable by the observer (Figure 2, right).

To put the presentation device to the test, we presented nine stimulus sets, each consisting of four different images or words (e.g., *enjoy*, *your*, *beer*, *mate*, each with a constant presentation duration of 25 ms, amounting to approximately 35 frames in our setup), to 10 observers. For each set, they had 1 minute of time to name the word on each strip. No further instructions were given, except the information that moving the eyes would be necessary. To our surprise, observers did extremely well: On average, 89% ($SD = 10\%$) of all words and 95% ($SD = 6\%$) of all pictures were correctly identified well below the time limit.

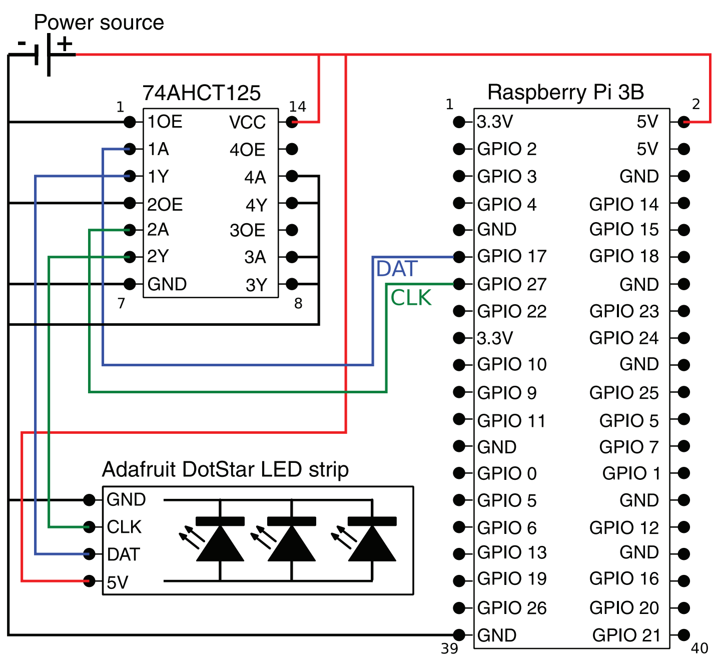

Figure 1. Minimal schematic for building the anorthoscopic presentation device. An Adafruit DotStar LED strip is controlled by a Raspberry Pi 3B via a 74AHCT125 level shifter. In addition, it would be advisable to use a 1000 μF capacitor to decouple the 5 V power supply.
Note: Please refer to the online version of the article to view the figures in colour.

Figure 2. Photographs of the anorthoscopic presentation using four Adafruit DotStar LED strips behind standard diffusors under static conditions (*left panel*) and when swiftly manually turning the camera to the right (*right panel*). Whereas brief vertical flashes are perceived during fixation, complex patterns, such as text become well visible during saccades. Photos were taken by Julius Krumbiegel, using a a Sony ILCE-7RM2 digital camera mounted on a revolvable tripod with a prolonged exposure time of 1/3 seconds to match the speed of the hand movement.
Note: Please refer to the online version of the article to view the figures in colour.

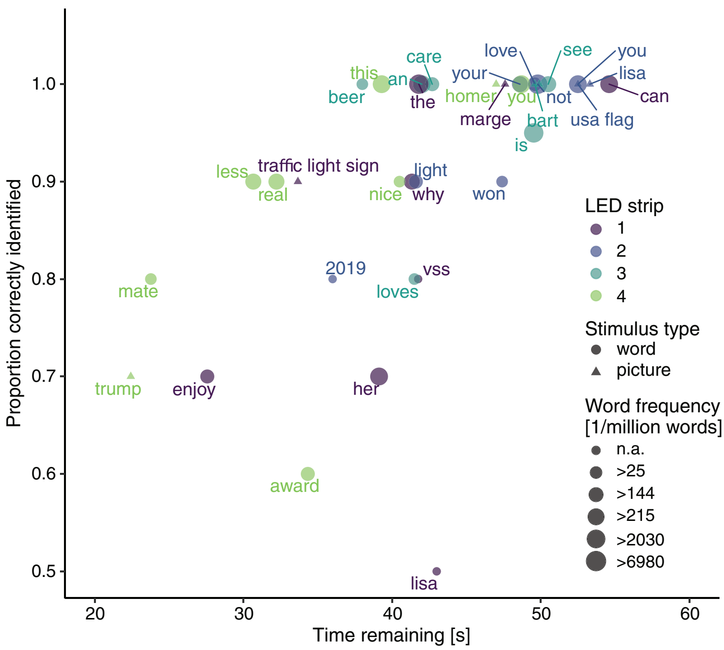

Figure 3. Mean proportion of correct stimulus identifications and corresponding time remaining (of each trial's 60-second deadline) across 10 observers. Seven trials involved word stimuli (circles), and in two trials, pictures were displayed (triangles). Word frequencies were based on the British National Corpus (Leech & Rayson, 2014).
Note: Please refer to the online version of the article to view the figures in colour.

It took participants a mean time of 29 seconds ($SD = 16$ seconds) to identify all four stimuli correctly. They identified pictures as well as short and frequent words with greater accuracy and speed (Figure 3). In incorrect trials, stimuli were rarely misidentified (<17% of incorrect trials, e.g., *night* instead of *light*, *now* instead of *won*), but could simply not be resolved. Participants' (spontaneous) strategies involved short, horizontal saccades at a high rate, often combined with rapid head movements. Notably, those observers strongly relying on combined head–eye movements did not exhibit any considerable increase in performance ($M_{head+eye} = 0.94$, $SD_{head+eye} = 0.07$; $M_{eye} = 0.91$, $SD_{eye} = 0.1$). Many also reported that stimuli suddenly clearly appeared as a result of an involuntary saccade, even while they were not actively attending to the LED strips.

This anorthoscopic presentation device demonstrates in visually striking manner that the inherent high velocities of human saccades can be utilized to efficiently paint text or images on the retina that are visible exclusively during saccades. The device is not only cost-effective (i.e., less than 200€ for a minimal setup with one LED strip) and easy to build (see schematics, Figure 1), but a list of components, as well as all code necessary to run the demo, including several test stimuli, can also be found online at https://github.com/richardschweitzer/IntrasaccadicRetinalPainting, empowering everybody to enjoy intrasaccadic retinal painting in the snugness of one's own living room.

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Author Contributions

T. W. initiated the project. J. W. designed and built the first prototype of the device and provided instructions. R. S. built the reported setup with four LED strips, implemented the presentation interface, and collected and analyzed reported data. R. S., M. R. and T. W. wrote and edited the manuscript.

Declaration of Conflicting Interests

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