Flicker effects on brain activity

Veitch, Jennifer A.

Publisher's version / Version de l'éditeur:

Lighting Design + Application (The magazine of the Illuminating Engineering Society of North America), 43, 12, pp. 56-59, 2013-12-01

Flicker Effects on Brain Activity
The emergence of solid-state lighting turns attention back to flicker

Jennifer A. Veitch
National Research Council of Canada

In the "bad old days" (25 and more years ago), most commercial and institutional interior lighting consisted of fluorescent lamps run on magnetic ballasts. This light source had an inherent flicker rate of 120 Hz in North America, where the mains AC supply operates at 60 Hz. There were variations in the amplitude of this flicker depending on the lamp type, but it was on the order of 17-40% [1]. Laboratory research found that these flicker conditions could disrupt saccadic eye movements [2], reduce visual performance [3] and reduce clerical work performance [4], always in comparison to fluorescent lamps operated on high-frequency electronic ballasts. A field investigation found that the incidence of headaches and eye-strain was lower when electronic ballasts were in use than when magnetic ones operated [5]. When electronic ballasts came into widespread use in the mid- to late-1990s, partly in response to energy-efficiency legislation, I and many other researchers turned to other topics. With most office lighting operating at >20 kHz, there seemed little reason to continue to study flicker.

That is, until solid-state lighting (SSL), and in particular light-emitting diodes (LEDs), came along. As with a fluorescent lamp, an LED requires a device (known as a driver) to modulate the current delivered to the diode. Unlike the binary choice between magnetic and electronic ballasts for fluorescent systems, there is no intrinsic flicker pattern associated with LED lighting [6], and currently-available products exhibit a wide variety of flicker patterns [7]. Knowing the history of research based on fluorescent lighting systems, a perceptive electrical engineer from Northeastern University, Prof. Brad Lehman, initiated a committee within IEEE to study the problem and to make recommendations for current modulation that would mitigate any possible harmful effects (IEEE PAR 1789, http://grouper.ieee.org/groups/1789). That committee is currently drafting its preliminary recommendations.

Involvement in that committee led my colleagues and me to begin again to study the effects of invisible, imperceptible flicker on viewers. What we know about the effects of flicker on reading, cognitive performance, and brain activity primarily comes from comparisons between 100 or 120 Hz fluorescent lamps on magnetic ballasts and 20-40 kHz fluorescent lamps on electronic ballasts. This generally showed that outcomes were poorer with lighting at the lower frequency flicker, but precisely why that might be the case was unknown. Little was known about the effects of flicker between these extremes. Previously, it was difficult to generate other flicker frequencies for experimental purposes and there was little practical reason to do so. Now, given the freedom available to electronics engineers to design LED drivers with almost any operating properties, this knowledge could be put to practical purpose.

Collaborative Effort
We formed a multi-disciplinary, multi-institution team to conduct this work, a collaboration between NRC (Dr. Jennifer Veitch, Mr. Greg Burns, and Dr. Erhan Dikel), Carleton University (Dr. Amedeo D'Angiulli and Ms Patricia Van Roon), the University of Essex (Prof. Arnold Wilkins), and Northeastern University (Prof. Brad Lehman). The work was financially supported by the National Research Council of Canada, the Clean Energy Fund (managed by Natural Resources Canada), OSRAM SYLVANIA, the J.H. McClung Lighrting Research Foundation, and Carleton University.

For our first experiment, we decided on a straightforward comparison of three flicker frequencies: 0 Hz (DC), 100 Hz, and 500 Hz, all with a square wave, 100% modulation, and a 50% duty cycle (Figure 1). By varying the number of chips and the voltage delivered, the system delivered a steady ~500 lx on the horizontal surface of the viewing booth regardless of the flicker condition. Based on the literature, we expected that 100 Hz flicker would cause problems in comparison to both 0 Hz and 500 Hz. The existing evidence suggested to us that low-frequency invisible flicker would disrupt eye movements (as compared to no flicker at all) and that it might cause irrelevant brain activity that would reduce cognitive performance. It seemed likely to us that 500 Hz would be a sufficiently high rate that the neural system would not be able to detect it; the highest rate at which flicker had been previously detected (at that time)

Originally published in *Lighting Design + Application*, Dec. 2013, vol. 43, No. 12, pp. 56-59

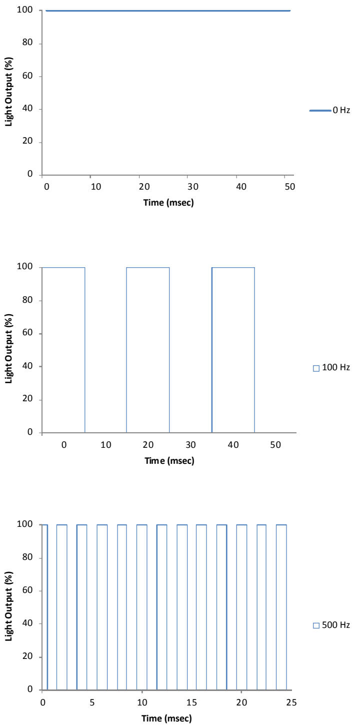


Figure 1. For the 0 Hz condition (top panel) light output was steady at 100%. For 100 Hz (center panel), light output varied between 0 and 100% 100 times per second with an equal time in the off and on state (50% duty cycle). For 500 Hz (bottom panel), light output varied between 0 and 100 % 500 times per second with an equal time in the off and on state (50% duty cycle).

was ~ 200 Hz. We chose 100 Hz rather than 120 Hz to ensure that we could distinguish this from any measurement artifacts related to the mains frequency.

Participants looked at a computer monitor in the booth that we had modified to use our LEDs as the light source, operating in synch with the overhead LEDs in the booth (Figure 2). We determined empirically that there was no visible “beat” between the (75 Hz) refresh rate of the monitor and any of the experimental conditions.

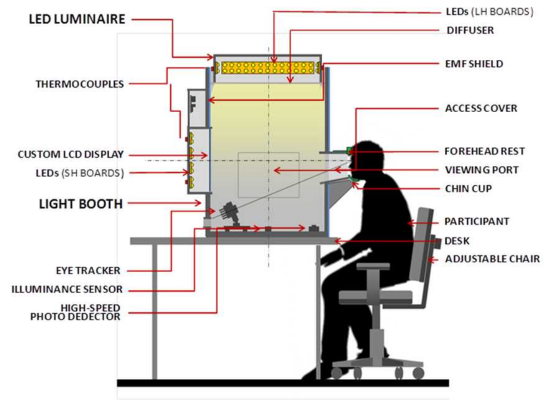


Figure 2. The participant looked at questionnaires and tasks on a vertically-mounted monitor in a custom booth, with all light sources controlled together.

Our experiment differed from others in using two measures of cognitive performance: sentence reading speed and Stroop task performance. The Stroop task requires the individual to respond to either the meaning of the presented word (RED, GREEN, YELLOW, BLUE) or the color in which it appears (red, green, yellow, blue) (Figure 3). Regardless of whether the task is to identify the color or the word, it takes more effort to respond when the color and word are incongruent (e.g., RED is shown in green text). Based on the previous research, we expected this increased effort to be even larger under 100 Hz than either 0 or 500 Hz. The extra effort could be manifested as either slower responding or lower accuracy for incongruent trials as compared to congruent ones.

During these tasks, we also recorded eye movements and brain activity. We used electro-encephalography [EEG] to study visual event-related potentials, which in this case means that we are examining the amplitude of brain activity that happens in the period immediately following a stimulus, such as the onset of the word in the Stroop task. The 68-channel EEG system also allowed us to examine the brain locations where activity was greatest.

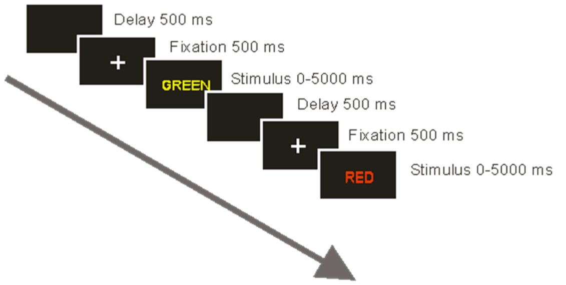
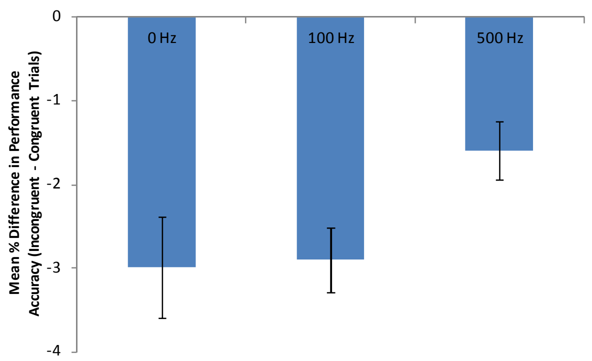


Figure 3. The task sequence for two trials of the Stroop task. Participants pressed a button indicating either the color of the word or its meaning, depending on the instruction. The first trial shown below is incongruent, and the second is congruent.

Early Results

The data analysis is under way now, and the results thus far are very interesting. The speed of reading sentences was the same regardless of the flicker condition. Measured using response time, the extra cognitive effort for an incongruent trial in the Stroop task was also the same regardless of flicker condition (i.e., there were no statistically significant differences). However, we also have a performance accuracy measure for the Stroop task. For all the conditions, performance accuracy was lower for incongruent than congruent trials (as expected), but this was not uniform across the flicker conditions. This measure showed that there was less cognitive effort for an incongruent Stroop trial under 500 Hz flicker than under 100 Hz flicker (Figure 4), with a moderately large, statistically-significant effect ($F(1,31) = 9.57$, $p<.01$, $\eta^2_{partial} = 0.24$). This is as we had predicted. What we had not predicted was that the cognitive effort effect would be the same under 0 Hz and 100 Hz operation (that is, that processing an incongruent color-word pair would be equally difficult under 0 Hz and 100 Hz). We will need to examine this effect in more detail; in any experiment, there are many ways to fail to find an effect because of problems with the experiment. However, these findings also have precedent in the neuroscience literature, where there are suggestions that noise in the system might improve cognitive processing under some conditions [8].

Figure 4. Cognitive effort was greater for the 0 Hz and 100 Hz conditions than for the 500 Hz condition, as seen in the larger drop in performance accuracy for incongruent trials compared to congruent ones. The chart shows means with the standard error of the mean.



We also have more work to do with these data. We have still to finalize the EEG analyses to look at the amplitude of responding to the onset of the stimuli. By conducting a fast-Fourier transform on the EEG recordings, we can also do the more traditional examination of the relative distribution of brain activity by wavebands (alpha, beta, delta, gamma or theta activity). The analyses of blinks and saccadic eye movements during the reading and Stroop tasks should, we expect, show disruptions during 100 Hz that replicate previous findings. Stay tuned for more information.

When we have completed the suite of analyses for this experiment, we will have added an important piece to the consideration of how LEDs ought to be operated, but clearly we will not have answered all the questions. Whereas the debate at present has focused on preventing adverse effects, another look at the information might lead us to the aim of creating favorable conditions for cognitive work. This needs to be approached very carefully, particularly given the evidence of differences in sensitivity to flicker and its role, for some people, as a trigger for headache and migraine. We need to understand the role of this cyclic variation in light output on many behavioral and physiological outcomes in order to make good decisions about the operating properties of light sources, both those in development today and any that may come in future.

About the author: Jennifer A. Veitch, PhD, Fellow IESNA, is a senior research officer at the National Research Council Canada (NRC). She's best known for her research on lighting quality, individual controls, and environmental and job satisfaction in open-plan offices. She is active in several professional associations and committees, including IEEE PAR1789. She serves on the IES Lighting Criteria Committee and is an Associate Editor of *Leukos*.

References

1. Wilkins, A.J. and C. Clark, *Modulation of light from fluorescent lamps.* Lighting Research and Technology, 1990. **22**(2): p. 103-109.
2. Wilkins, A.J., *Intermittent illumination from visual display units and fluorescent lighting affects movement of the eyes across text.* Human Factors, 1986. **28**(1): p. 75-81.
3. Veitch, J.A. and S.L. McColl, *Modulation of fluorescent light: Flicker rate and light source effects on visual performance and visual comfort.* Lighting Research and Technology, 1995. **27**(4): p. 243-256.
4. Veitch, J.A. and G.R. Newsham, *Lighting quality and energy-efficiency effects on task performance, mood, health, satisfaction and comfort.* Journal of the Illuminating Engineering Society, 1998. **27**(1): p. 107-129.
5. Wilkins, A.J., et al., *Fluorescent lighting, headaches and eyestrain.* Lighting Research and Technology, 1989. **21**(1): p. 11-18.
6. Wilkins, A.J., J.A. Veitch, and B. Lehman, *LED lighting flicker and potential health concerns: IEEE Standard PAR1789 update*, in *Proceedings of the Energy Conversion Congress and Exposition (ECCE) 2010 IEEE, 12-16 Sept., 2010*2010, Institute of Electrical and Electronics Engineers: Piscataway, NJ. p. 171-178.
7. Poplawski, M. and N.J. Miller, *Exploring flicker in solid-state lighting: What you might find, and how to deal with it*, in *Illuminating Engineering Society of North America Annual Conference*2011, October: Austin, TX.
8. McDonnell, M.D. and L.M. Ward, *The benefits of noise in neural systems: bridging theory and experiment.* Nature Reviews Neuroscience, 2011. **12**(7): p. 415-426.