

Introduction to Flicker Concepts and Effects

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ENERGY STAR[®] Flicker Testing Tutorial

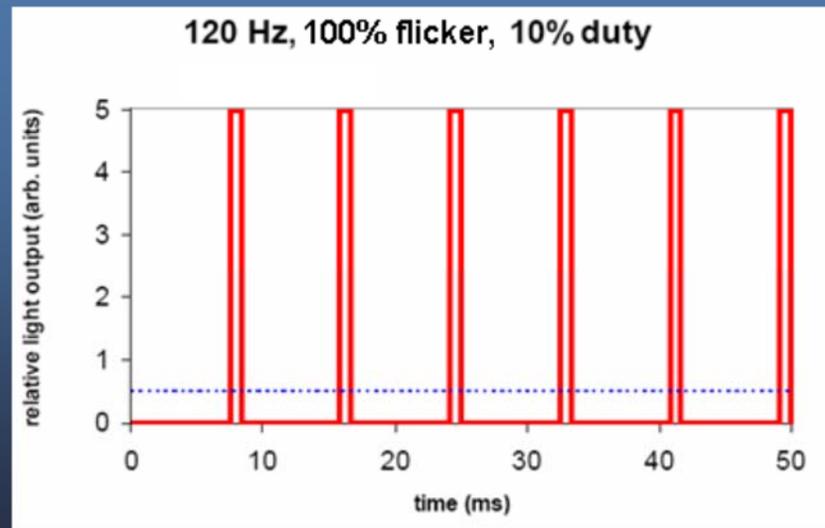
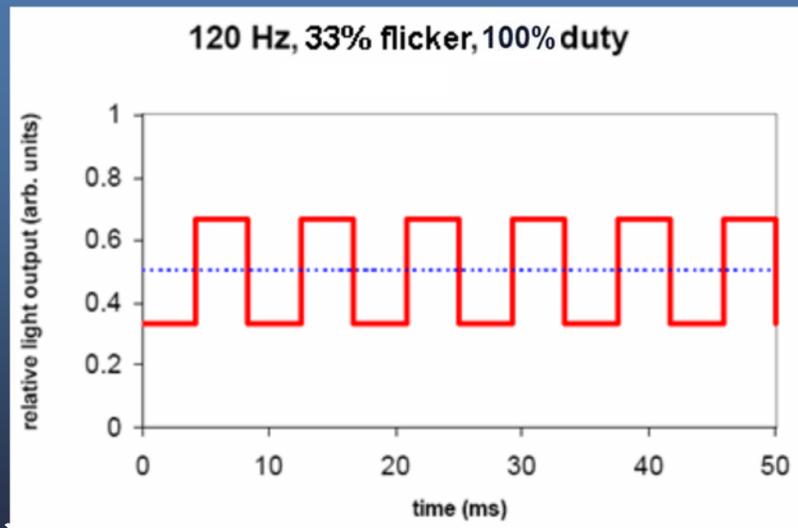
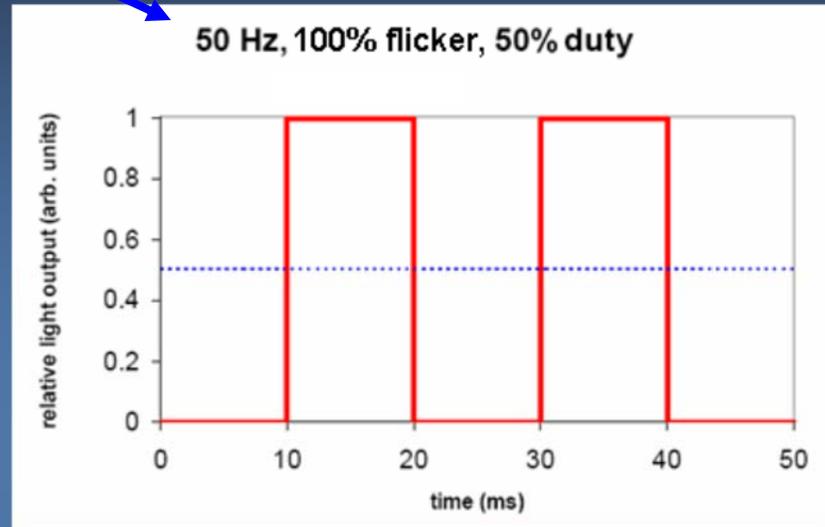
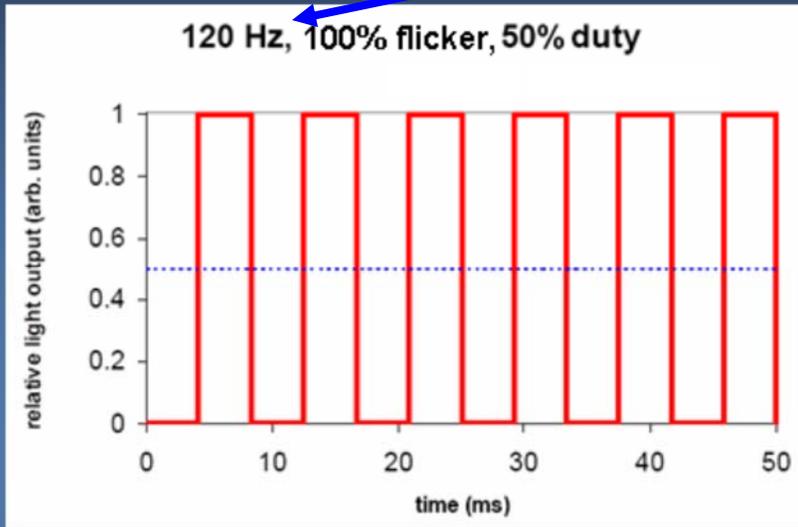
September 22, 2017

Introduction

- ◆ Visual sensitivity to flicker can be characterized in two ways:
 - › *Direct* perception of light modulation
 - › *Indirect* perception of stroboscopic effects (phantom array, wagon-wheel effect)
- ◆ Characteristics of flicker that might influence perception include:
 - › Frequency
 - › Modulation depth
 - › Duty cycle
 - › Waveform shape

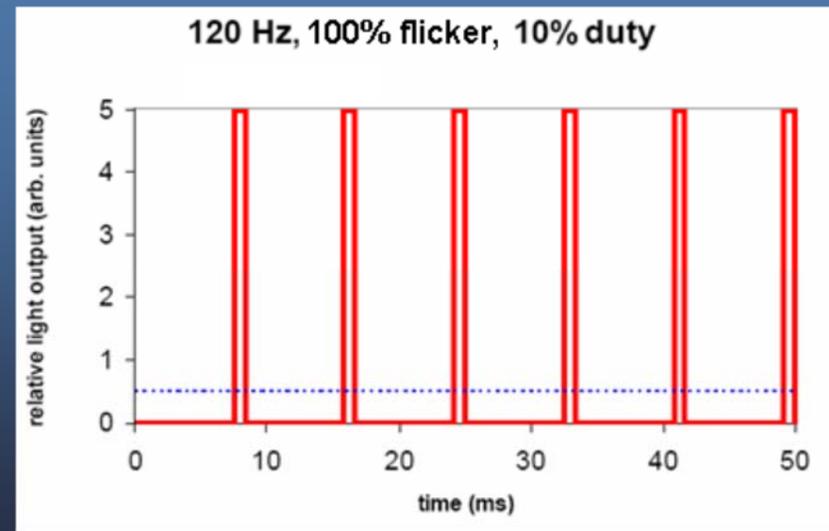
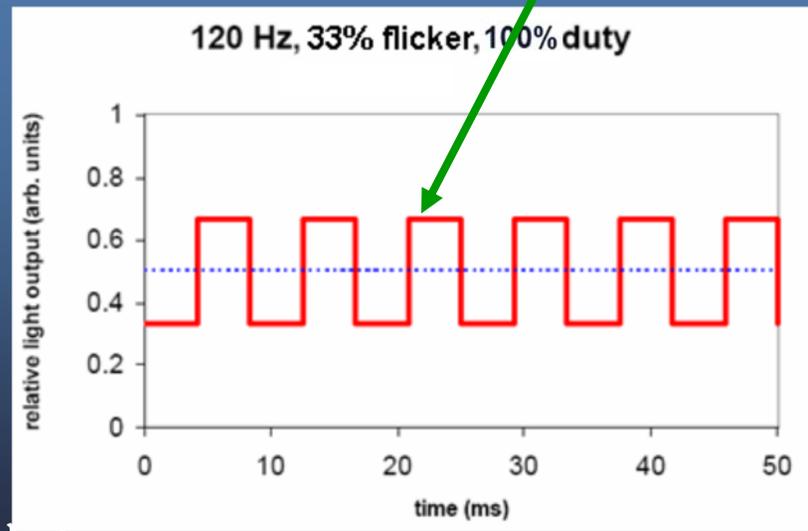
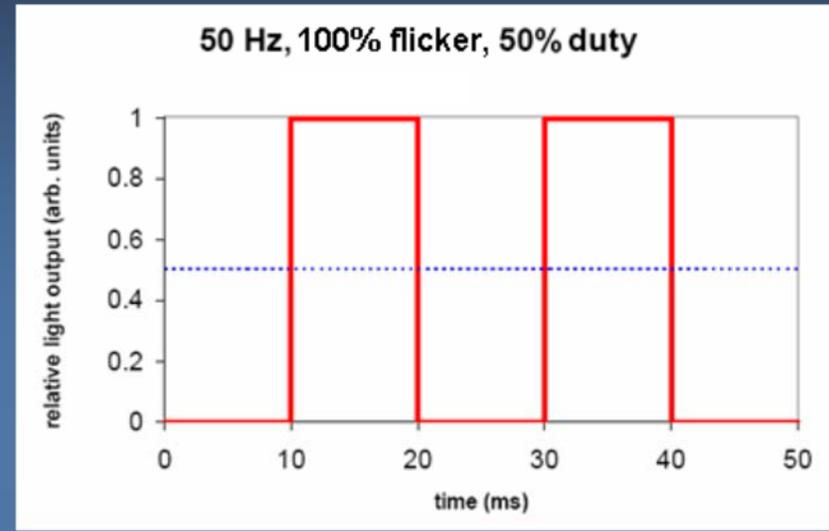
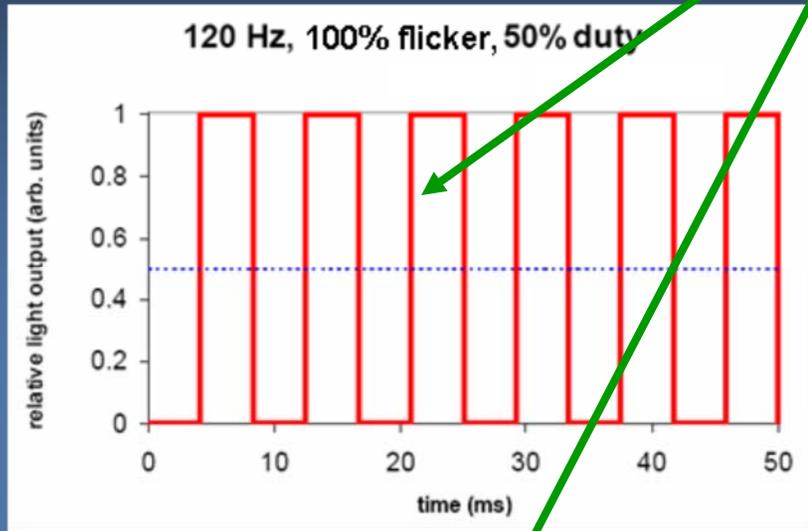
Flicker Terminology

Frequency (cycles per second)



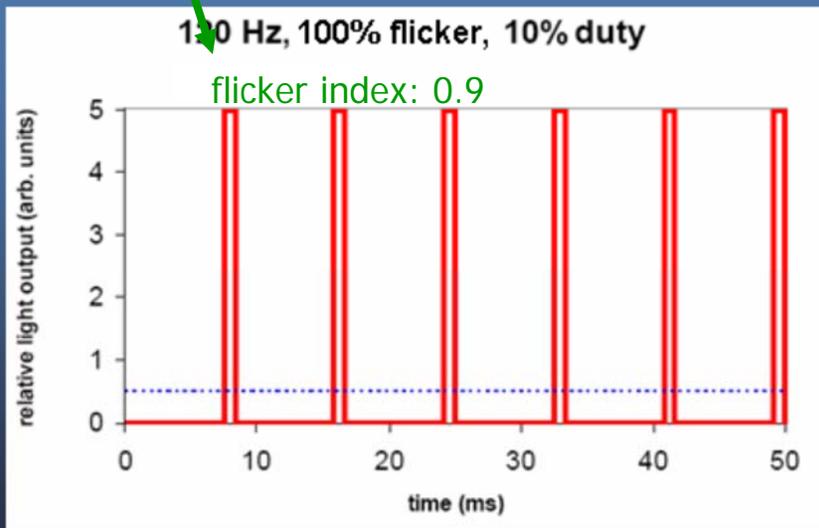
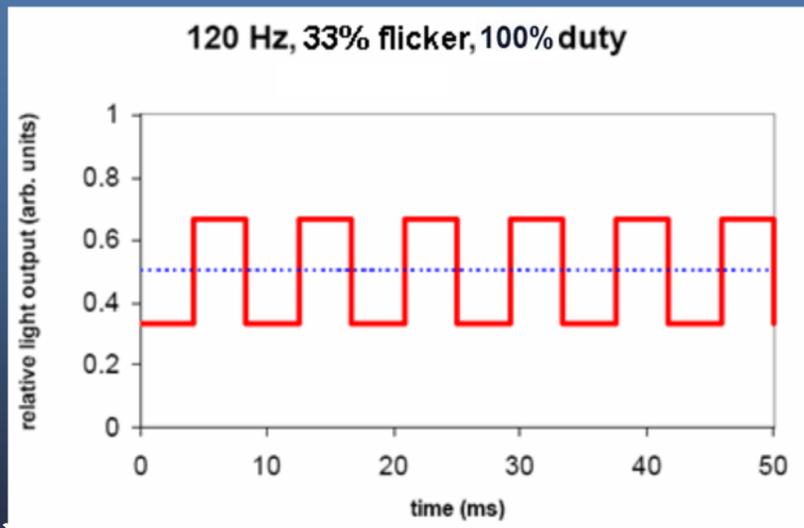
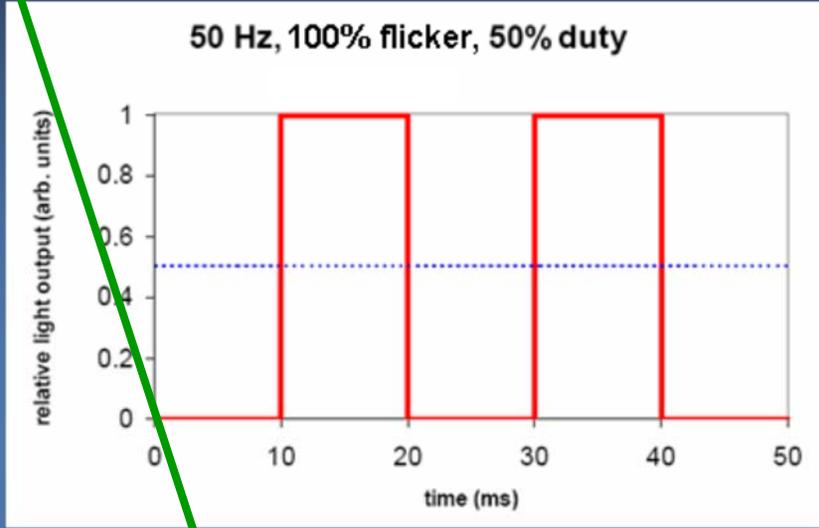
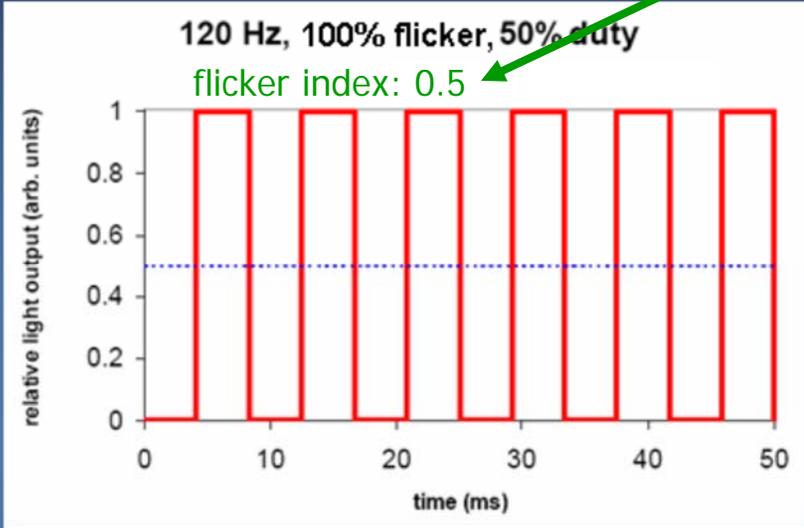
Flicker Terminology

Modulation amount
(Percent flicker:
 $[max-min]/[max+min]$)



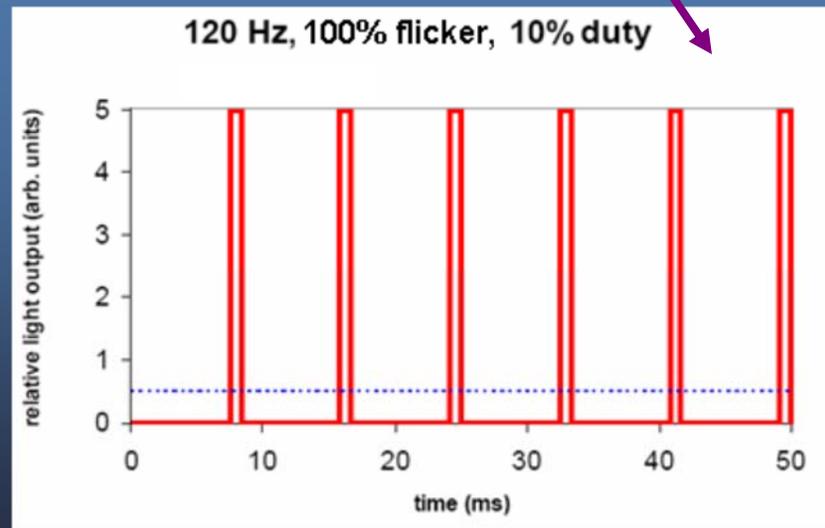
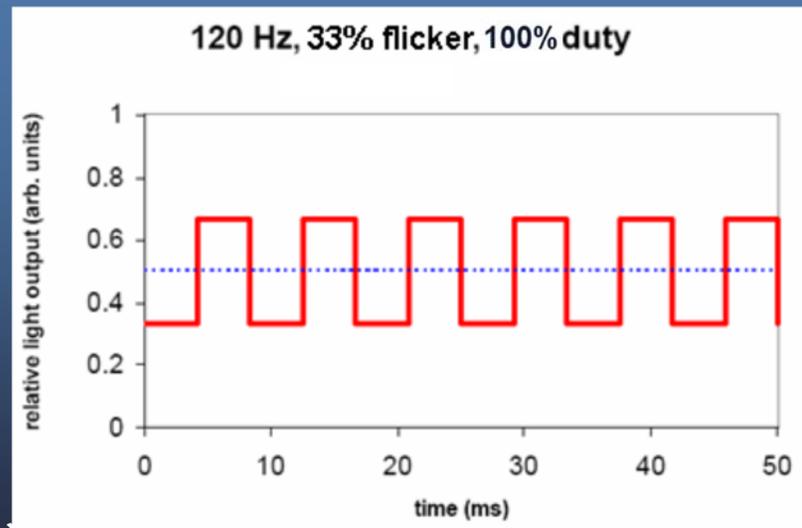
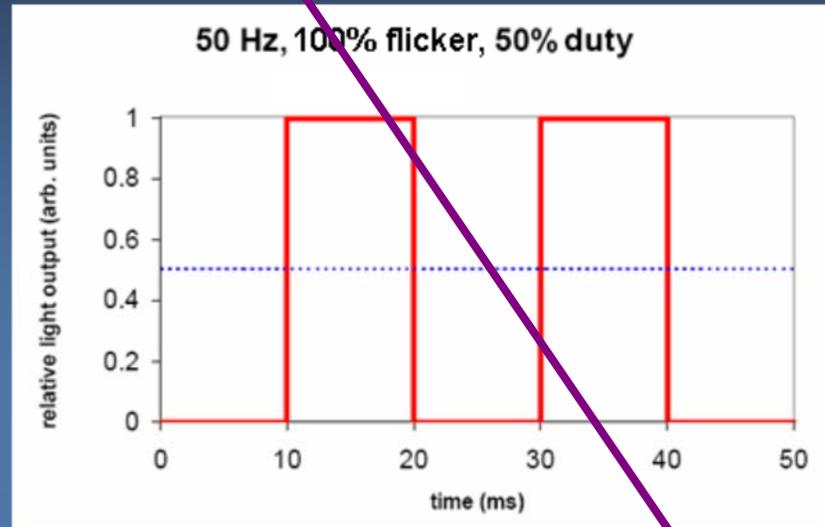
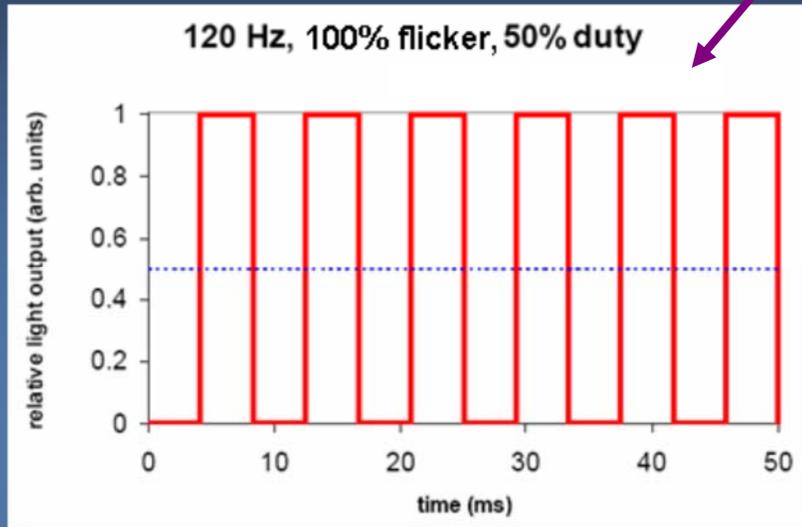
Flicker Terminology

Modulation amount
(Flicker index: area above average/total area)



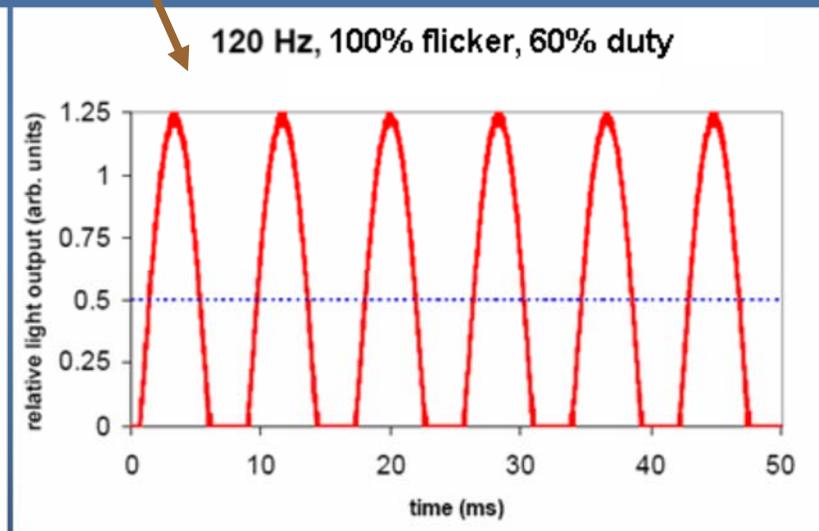
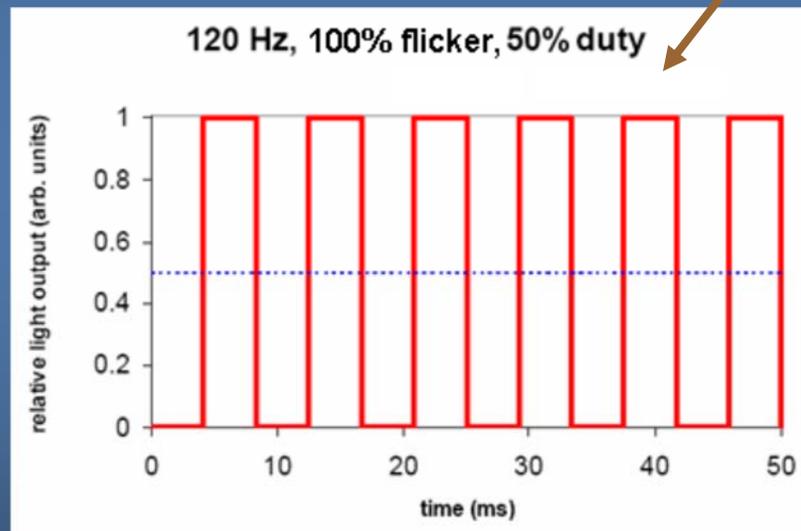
Flicker Terminology

Duty cycle (% of time light output > 10% of max)



Flicker Terminology

Waveform shape
(rectangular vs. sinusoidal)



Initial Study: Lighting Conditions Tested

Condition	Flicker Frequency (Hz)	Percent Flicker (%)	Flicker Index	Duty Cycle (%)*	Waveform	Correlated Colour Temperature (K)
1	50	100%	0.50	50%	Rectangular	4000
2	60	100%	0.50	50%	Rectangular	4000
3	100	100%	0.50	50%	Rectangular	4000
4	120	100%	0.50	50%	Rectangular	4000
5	300	100%	0.50	50%	Rectangular	4000
6	120	100%	0.90	10%	Rectangular	4000
7	120	33%	0.17	50%	Rectangular	4000
8	120	100%	0.41	60%	Chopped sinewave	6000
9	120	100%	0.90	10%	Rectangular	2700

*Percentage of time light output > 10% of maximum.

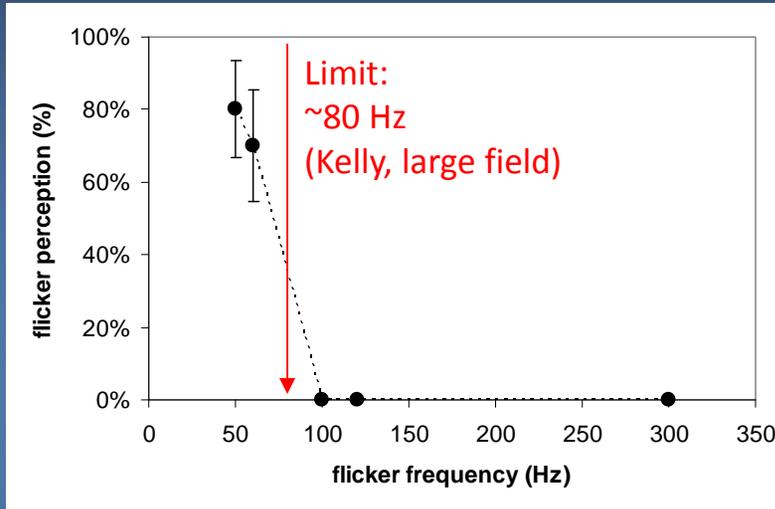
- ◆ Frequency: Conditions 1-5
- ◆ Modulation amount: Conditions 4, 7
- ◆ Duty cycle: Conditions 4, 6
- ◆ Waveform shape: Conditions 4, 8
- ◆ CCT: Conditions 6, 9



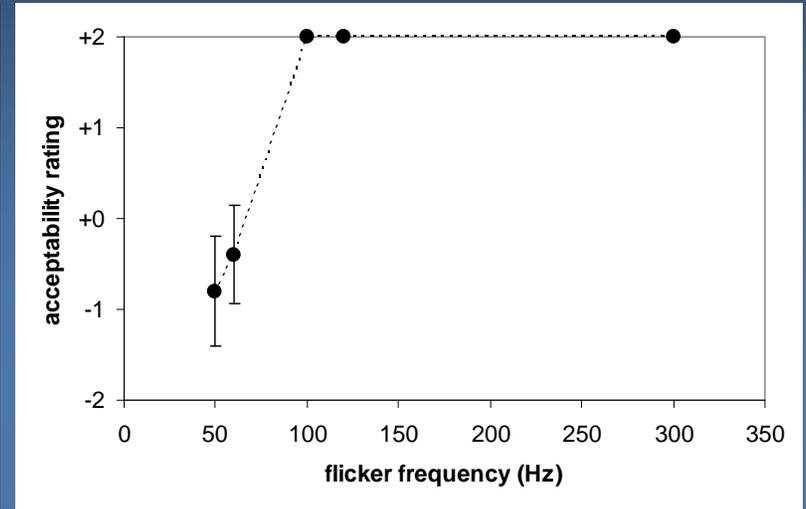
Results: Frequency

100% Flicker (0.5 Flicker Index)
50% Duty Cycle
Rectangular Waveform Shape
4000 K CCT

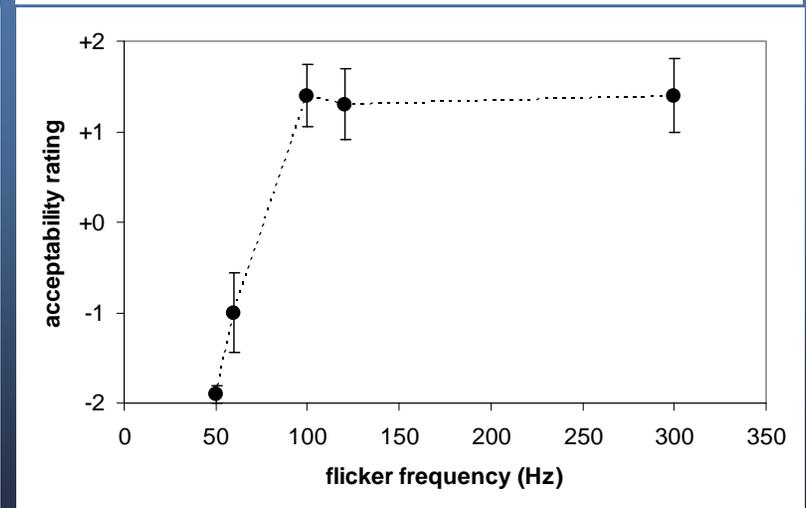
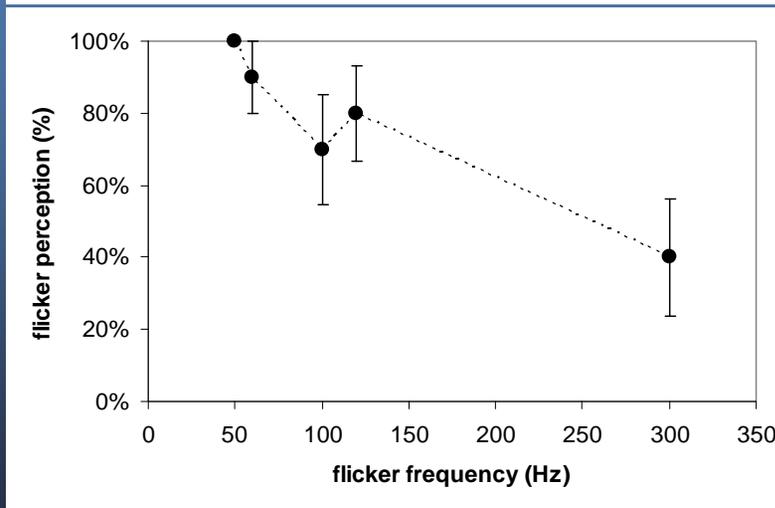
detection (%)



acceptability



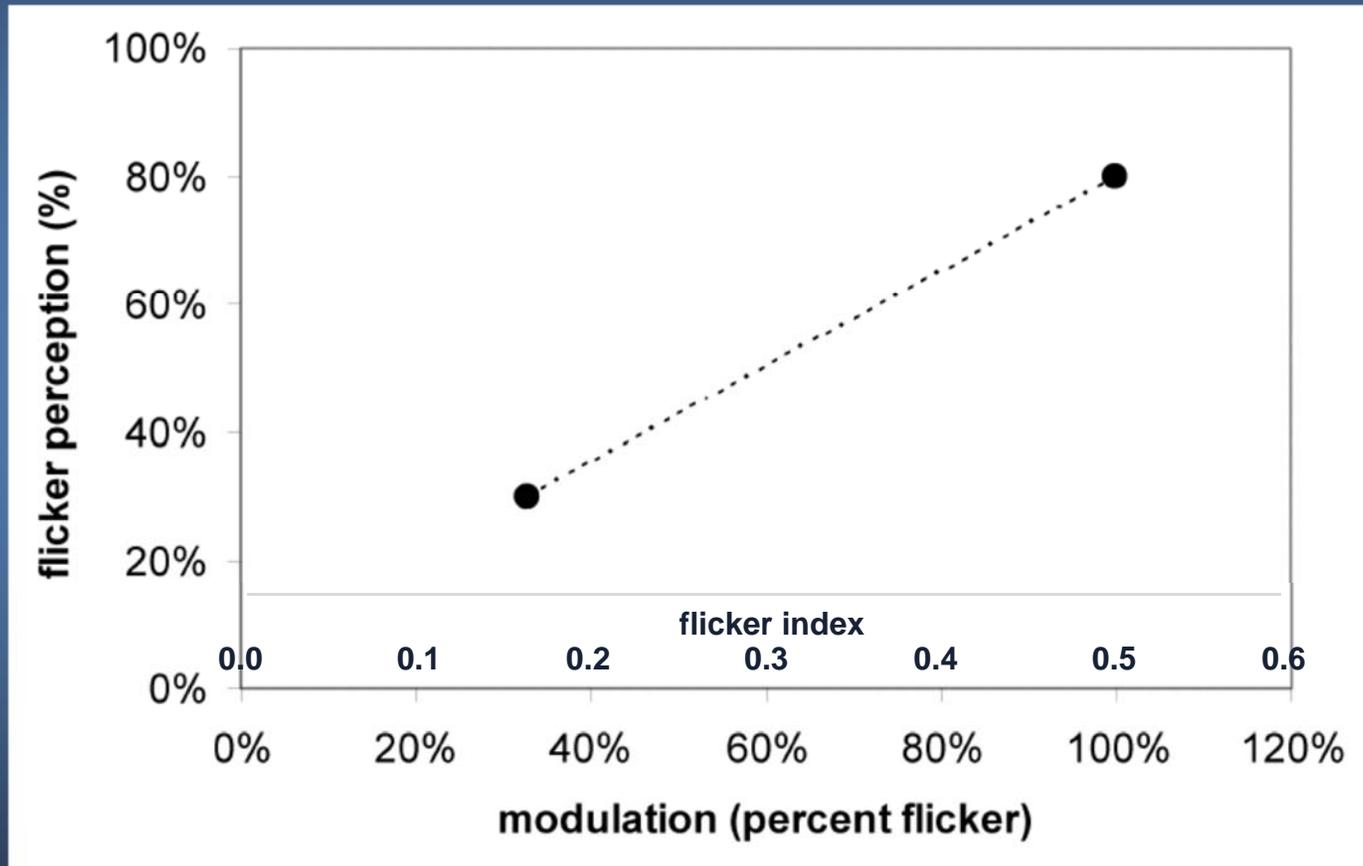
Q: flicker while waving hand under luminaire ($p < 0.05$)



Results: Modulation Amount

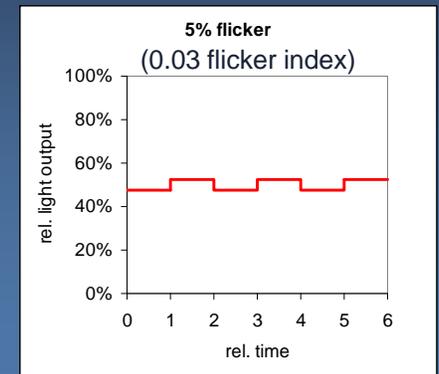
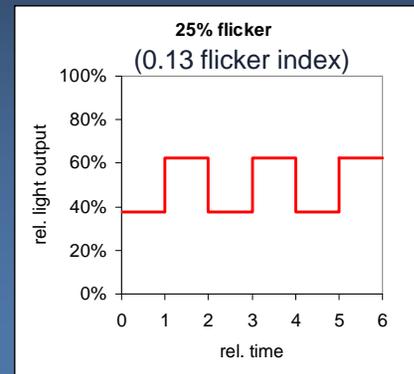
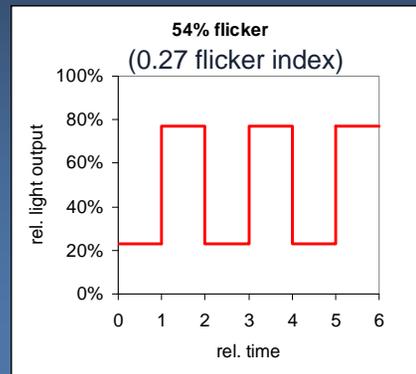
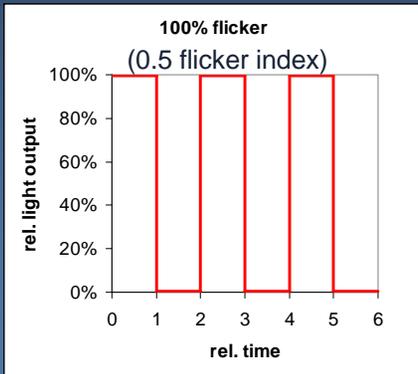
120 Hz Frequency
50% Duty Cycle (modulation only)
Rectangular Waveform Shape
4000 K CCT

detection (%)



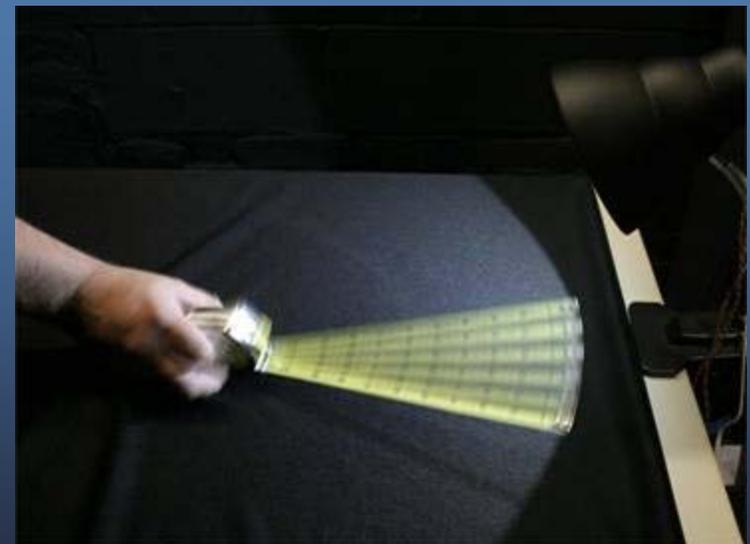
Q: flicker while waving hand under luminaire ($p < 0.05$)

Parametric Study: Detection/Acceptability of Stroboscopic Effects

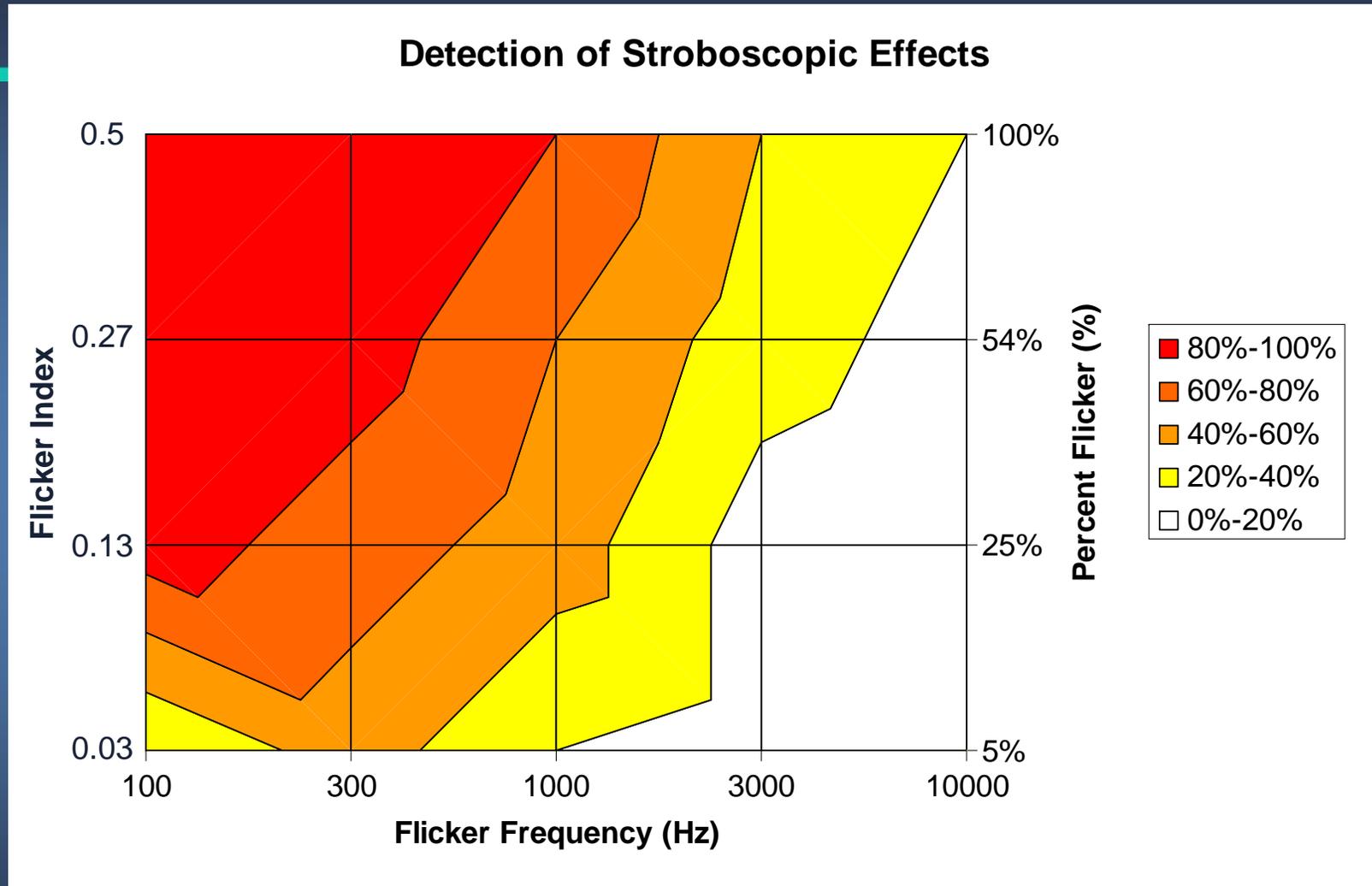


Experimental Task: Waving a light-colored rod against a dark background

Frequency → Percent flicker (flicker index) ↓	100 Hz	300 Hz	1000 Hz	3000 Hz	10000 Hz
100% (0.5)					
54% (0.27)					
25% (0.13)					
5% (0.03)					



Results: Did You See It?

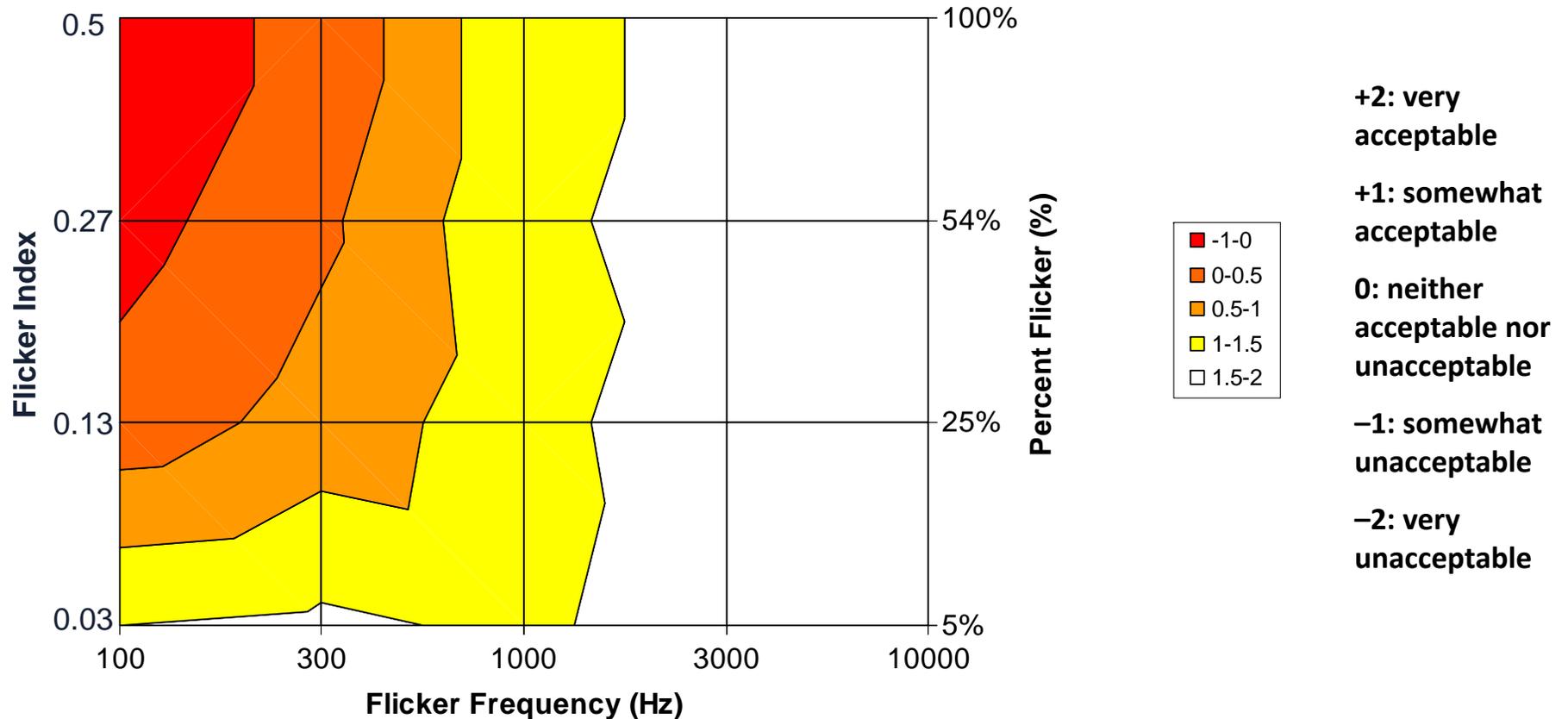


$$d = [(25p + 140)/(f + 25p + 140)] \times 100\%$$

(d=%detection, f=frequency in Hz, p=percent flicker=flicker index × 200)

Results: Was it Acceptable?

Acceptability of Stroboscopic Effects

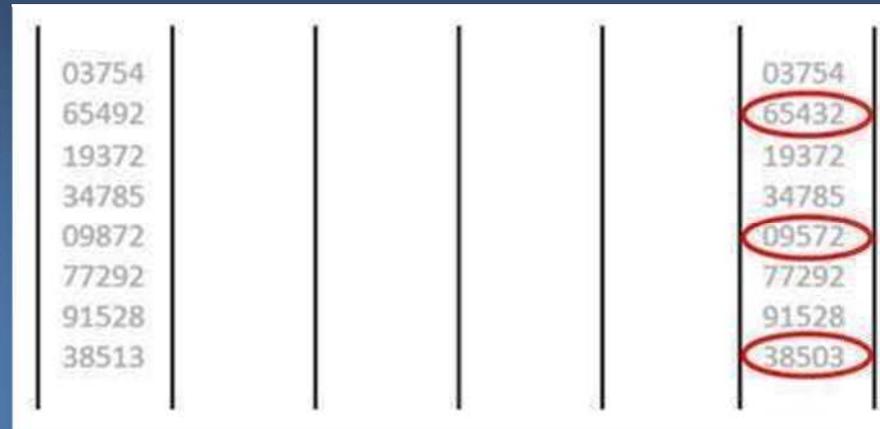


$$a = 2 - 4/[1 + f/(130 \log p - 73)]$$

(a=rating value, f=frequency in Hz, p=percent flicker=flicker index × 200)

Visual Performance Study

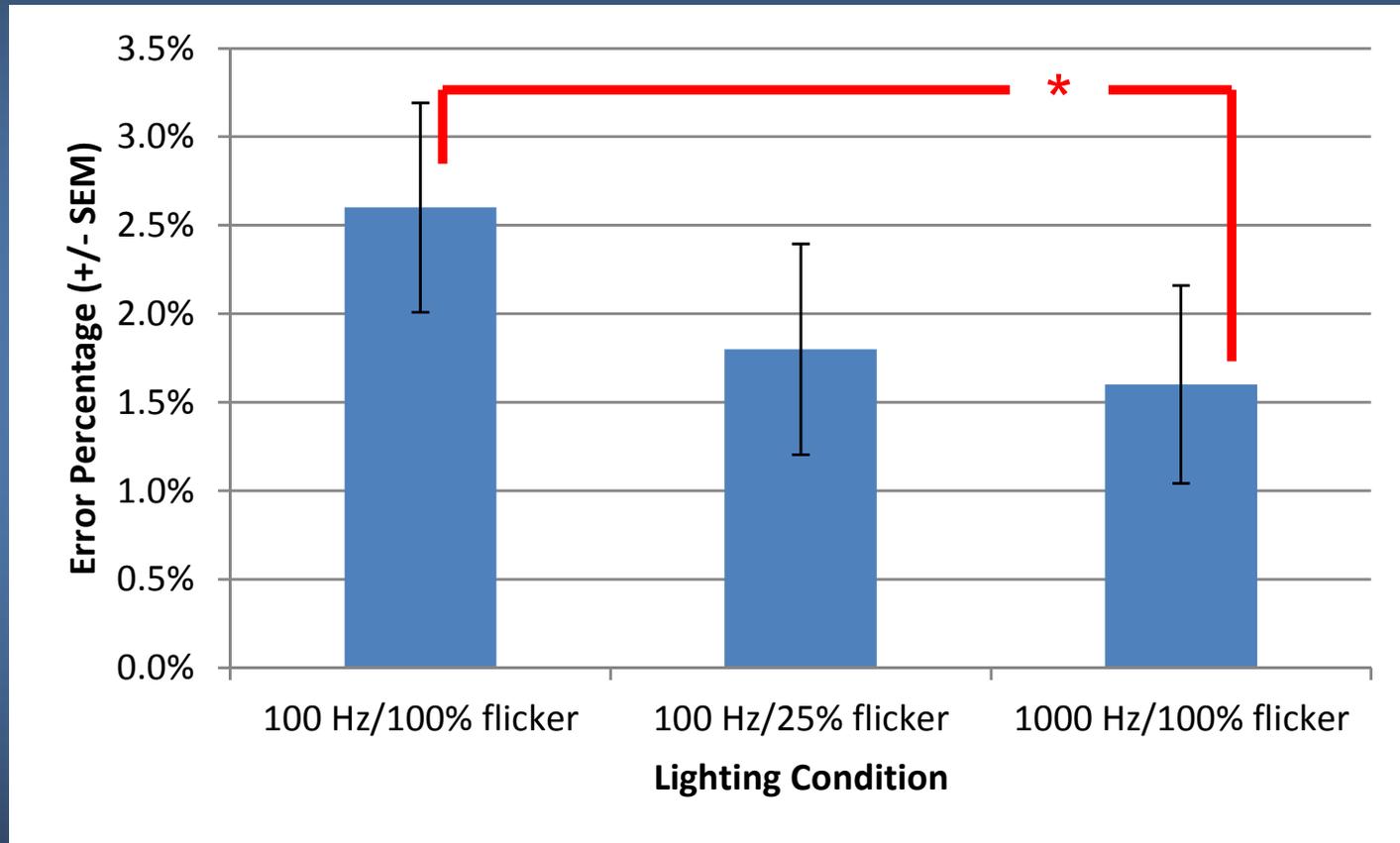
- ◆ Three flickering lighting conditions:
 - 100 Hz/100% flicker (0.5 flicker index):
96% detection, -0.6 acceptability
 - 100 Hz/25% flicker (0.13 flicker index):
88% detection, -0.1 acceptability
 - 1000 Hz/100% flicker (0.5 flicker index):
73% detection, +1.4 acceptability



- ◆ Participants performed a low-contrast numerical verification task, identifying mismatched 5-digit numbers over 30 minutes
- ◆ Number of lines completed, number and rate of errors, and subjective comfort ratings were recorded

(Bullough et al. 2013)

Visual Performance Study: Results



Task-Dependent Response Study: Experimental Setup

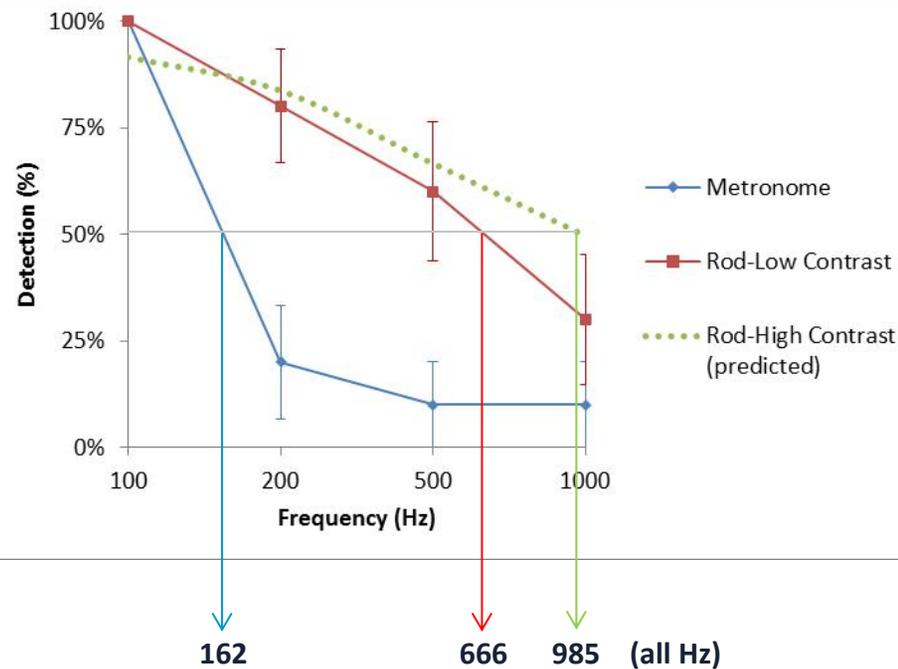
- ◆ Horizontal illuminance on desktop:
300 lx
- ◆ Light-colored surfaces
- ◆ Flicker frequencies (**always at 33% flicker, 0.17 flicker index**):
 - › 100, 200, 500, 1000 Hz
- ◆ Questions:
 - › Stroboscopic effects detected while waving white rod?
 - › Stroboscopic effects detected with metronome (208 bpm)?
 - › Acceptability of any flicker from lighting?



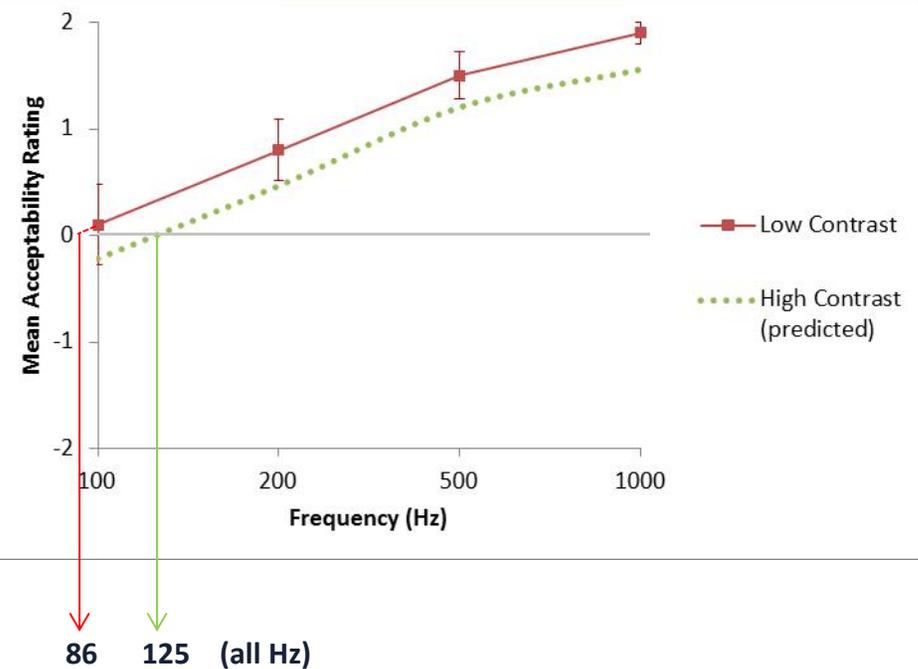
+2	Very acceptable
+1	Somewhat acceptable
0	Neither acceptable nor unacceptable
-1	Somewhat unacceptable
-2	Very unacceptable

Experimental Threshold Results

Detection



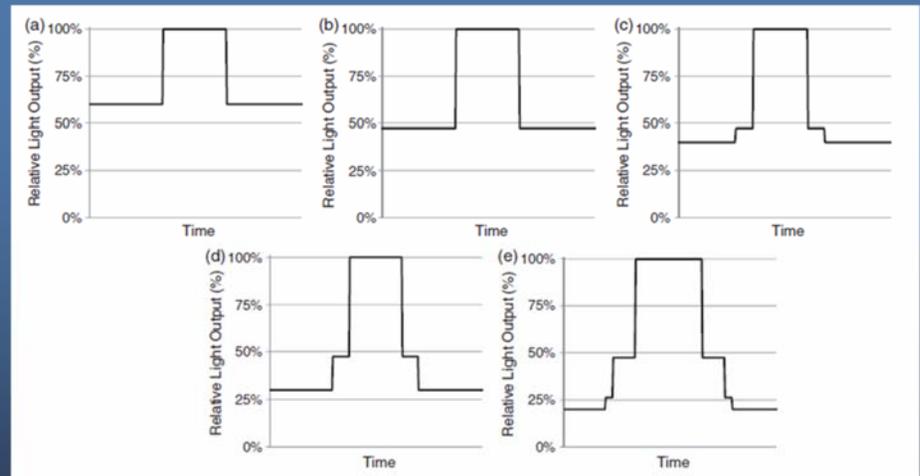
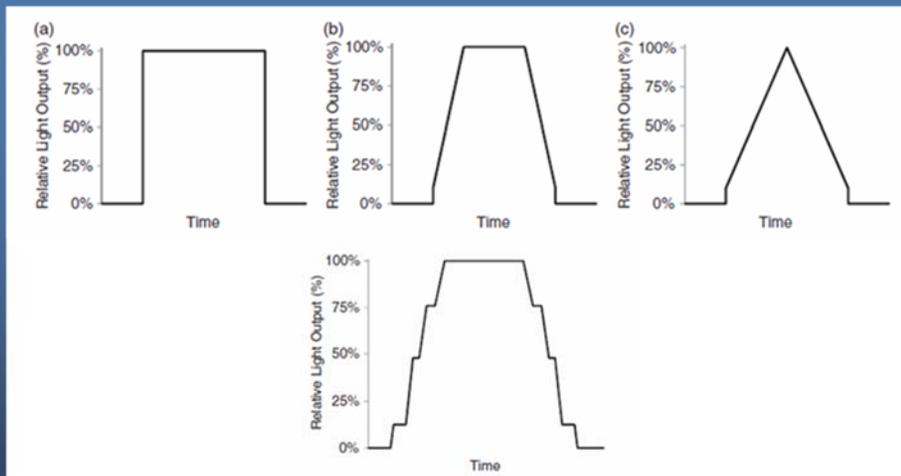
Acceptability



Thresholds for detection (50%) and for acceptability (rating=0) occurred at systematically lower frequencies with lower contrast and slower movement speed. In other words, sensitivity to stroboscopic effects was reduced under the tested conditions (e.g., lower contrast, slower movement) relative to those used to develop the predictions by Bullough et al. (2012)

Other (Non-Rectangular) Waveform Shapes

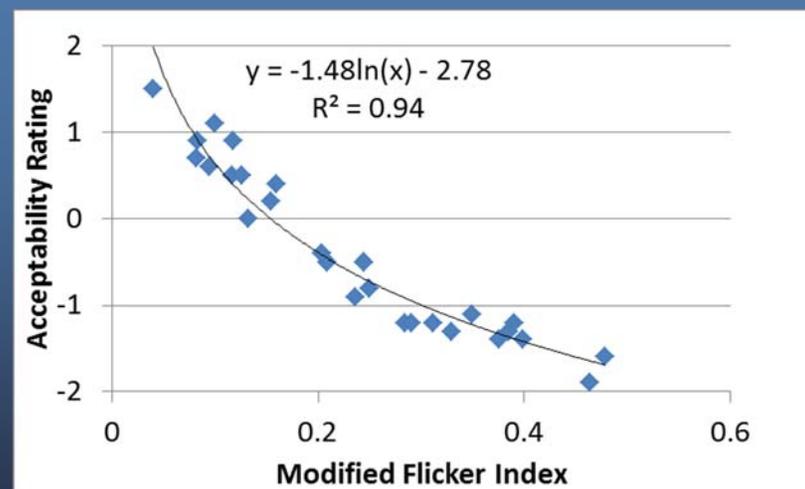
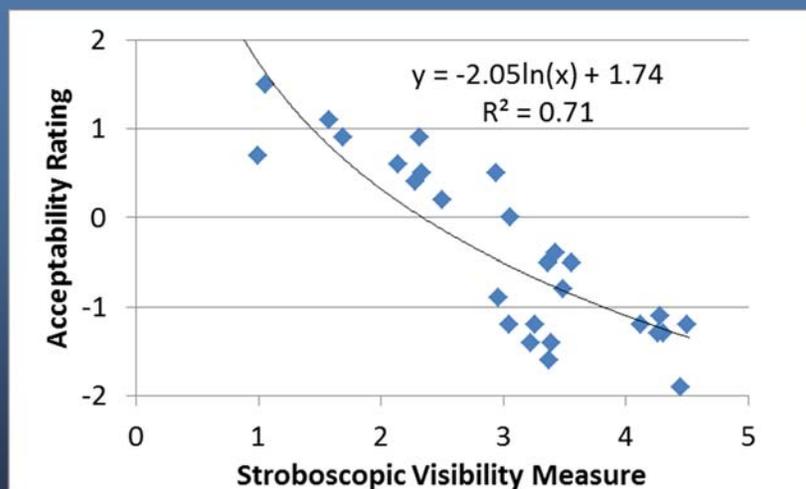
- ◆ Bullough and Marcus (2015) evaluated different waveform shapes and duty cycle (60%-90% or 100%) at 100, 120, 300 and 1000 Hz
- ◆ Responses to waving a light-colored rod against a dark background, and to a metronome operating at 208 bpm were assessed



[all waveforms above: 100% flicker]

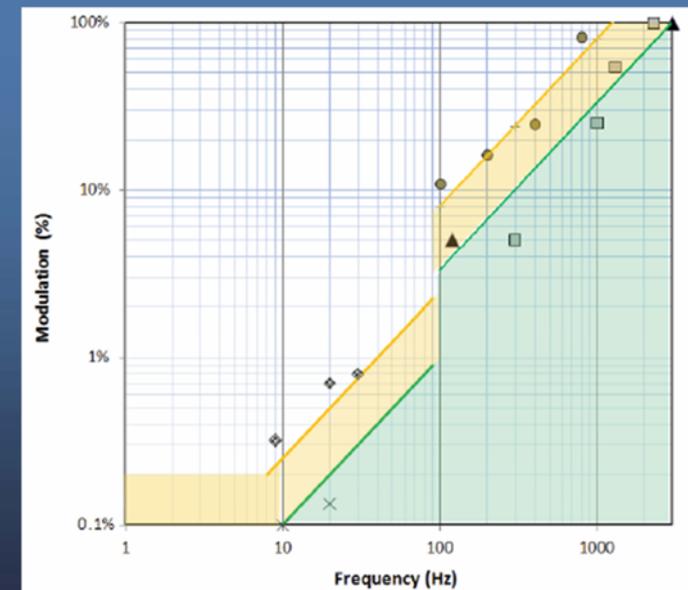
Experimental Results

- ◆ Percent flicker and flicker index values cannot be compared across different frequencies; Perz et al. (2015) developed a stroboscopic visibility measure (SVM) based on Fourier analysis, which is independent of frequency properties
- ◆ In their study of responses to 100-1000 Hz flicker varying in waveform shape and duty cycle (Bullough and Marcus 2015), detection and acceptability were rectified at least as well as SVM by a **modified flicker index** defined as:
 - **Modified flicker index** = Flicker index $\times 100/f$, where f is the frequency (Hz)



Implications of Results

- ◆ Data from Bullough and Marcus (2015) have several implications for specifications to limit perception of stroboscopic effects:
 - Metrics based on flicker index (such as modified flicker index) are superior to those based on percent flicker, such as IEEE 1789 and California Title 24
 - For waveforms with more than one fundamental frequency component, modified flicker index is difficult to implement because no single frequency can be defined



Discussion

- ◆ Stroboscopic effects can be visible at frequencies of 1000 Hz or higher
 - › High contrast and rapid movement maximize detection
- ◆ However, even when seen, stroboscopic effects are not necessarily unacceptable
- ◆ Metrics based on percent flicker and flicker index are limited to waveforms with a single dominant frequency
 - › Fourier-based metrics would provide a more complete characterization of complex waveforms

Thank you!

◆ Acknowledgments

- › ASSIST program sponsors
- › US Environmental Protection Agency
- › LRC faculty, staff and students

Questions?

<http://www.lrc.rpi.edu/programs/solidstate/assist/recommends/flicker.asp>

