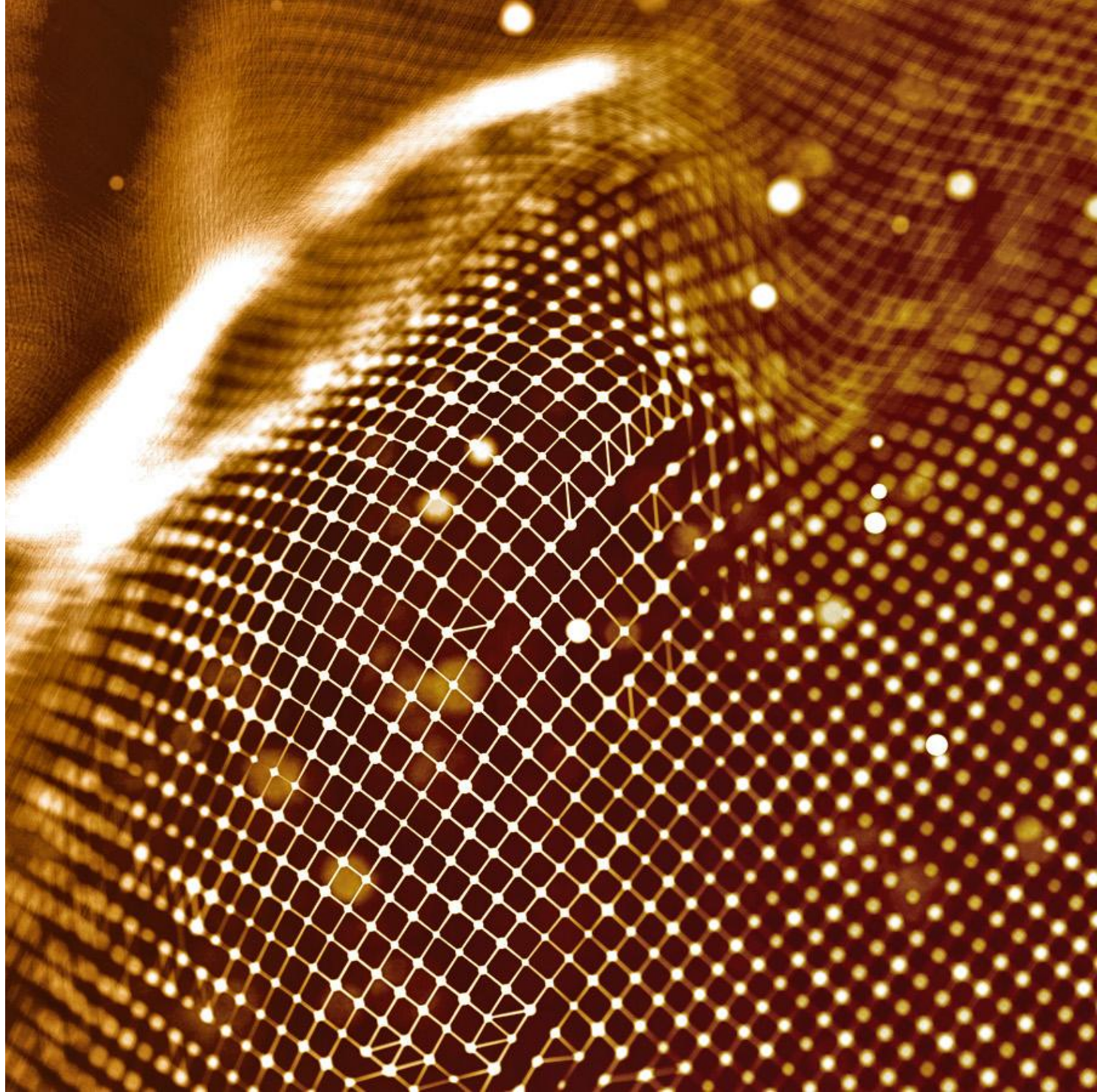
Pacific Northwest
NATIONAL LABORATORY

Flicker:

New results of work on the phantom array effect using participants with and without migraine

Michael Royer & Naomi Miller



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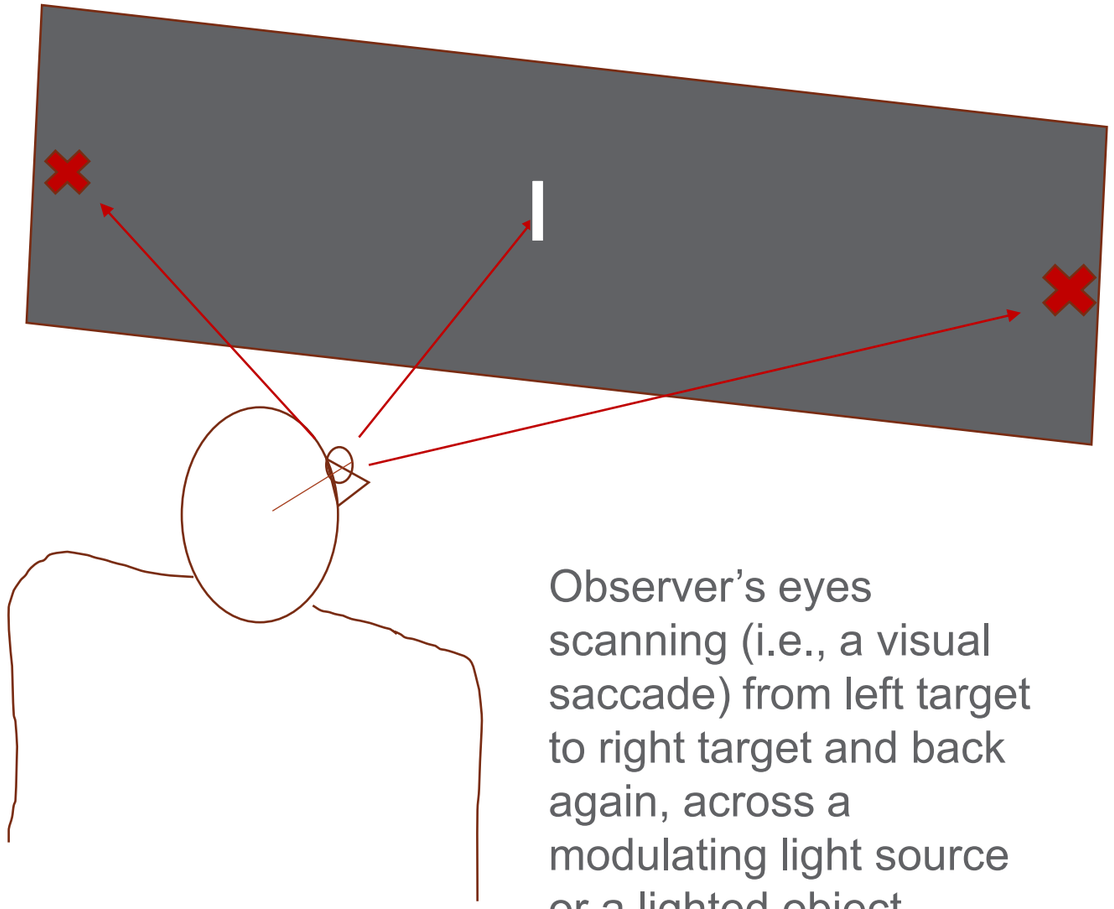
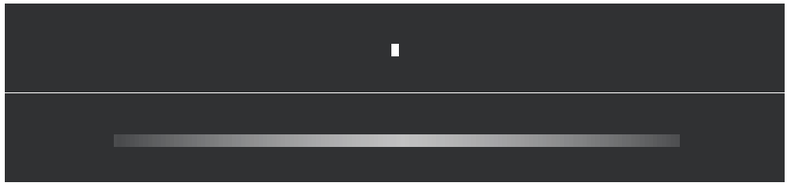
Phantom array effect – How it might look when scanning across the modulating light source

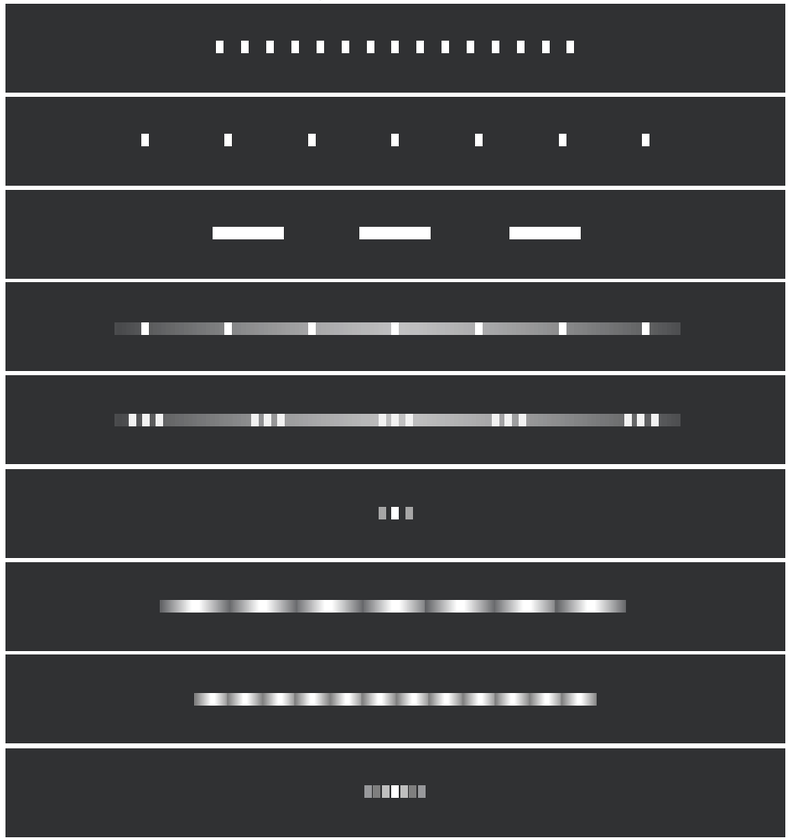


Observer's eyes scanning (i.e., a visual saccade) from left target to right target and back again, across a modulating light source or a lighted object

NO - Phantom Array Not Visible



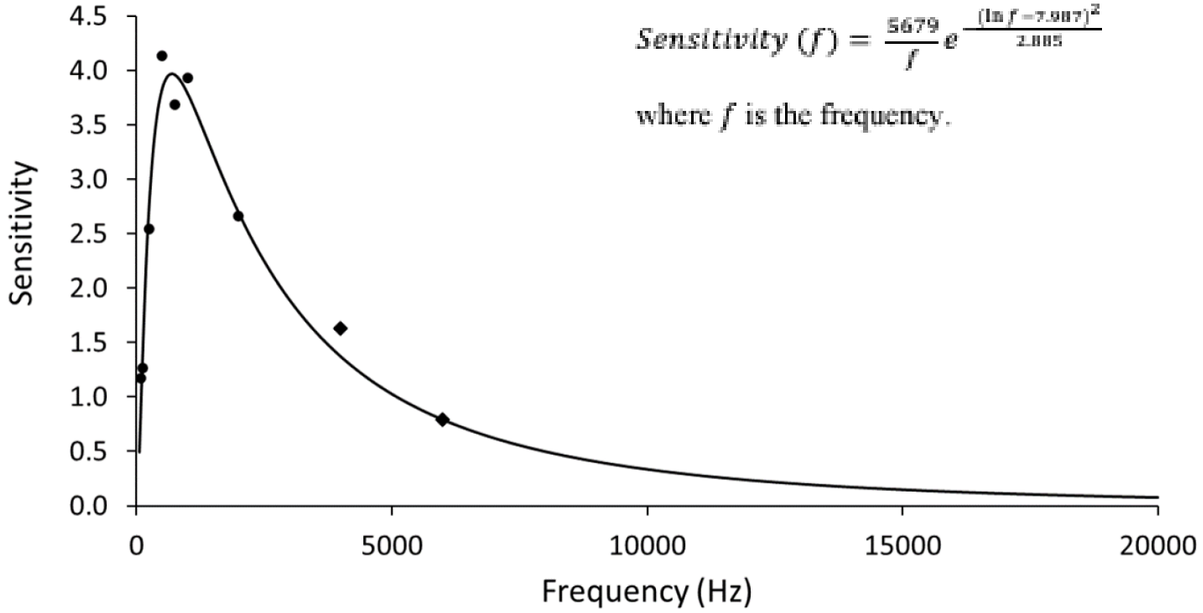
YES - Phantom Array Visible



Phantom Array Visibility Measure (PAVM)

$$PAVM = \sqrt[2.1]{\sum_{m=1}^{\infty}(C_m \cdot S_m)^{2.1}} \begin{cases} < 1, & not\ visible \\ = 1, & just\ visible \\ > 1, & visible \end{cases}$$

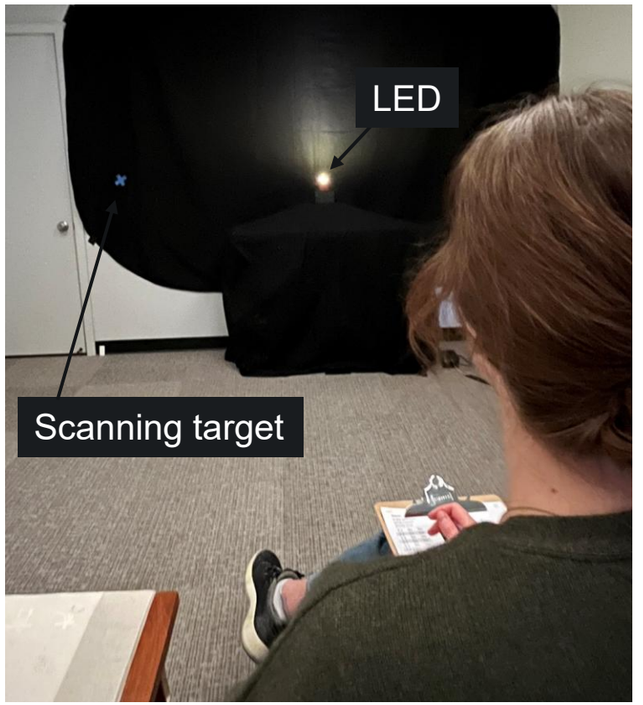
C_m =amplitude of the m^{th} Fourier component of a TLM waveform divided by the direct current (DC) value of the waveform, S_m is the sensitivity value of visibility for a sinusoidal wave at the frequency of the m^{th} Fourier component, calculated from a time-domain threshold visibility function.

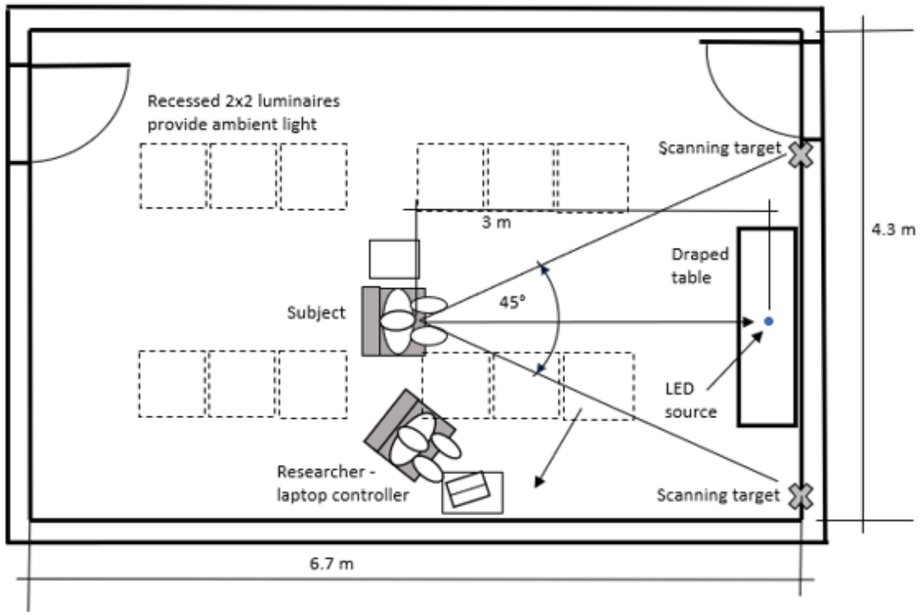


https://journals.sagepub.com/doi/abs/10.1177/14771535241239611

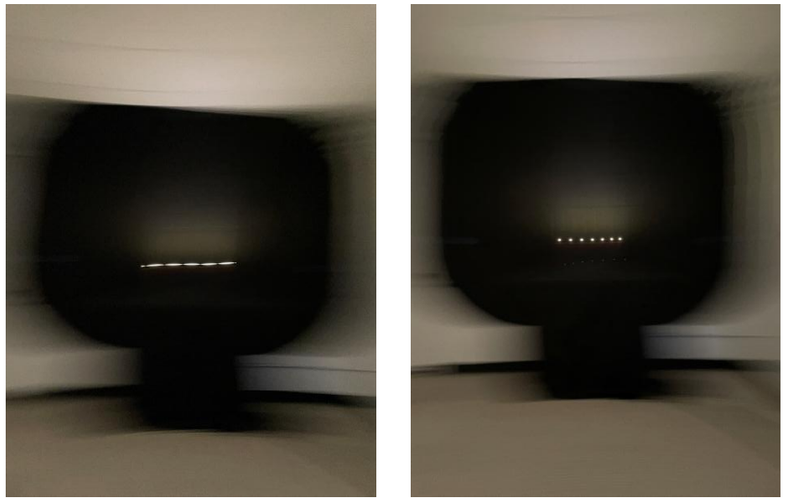
PNNL 2024 PAE Experiment

1. Additional data on PAE visibility over wide range of stimuli
2. New data on PAE annoyance
3. Test previously developed PAVM
4. Compare sensitivity of migraineur and non-migraineur participants.
5. New data on adverse physiological reactions and behaviors





- 3 m (10’) viewing distance from subject eye to LED
- 11 lux at eye, including ambient light
- 19 lux avg. horizontal at 0.76 m work plane height.

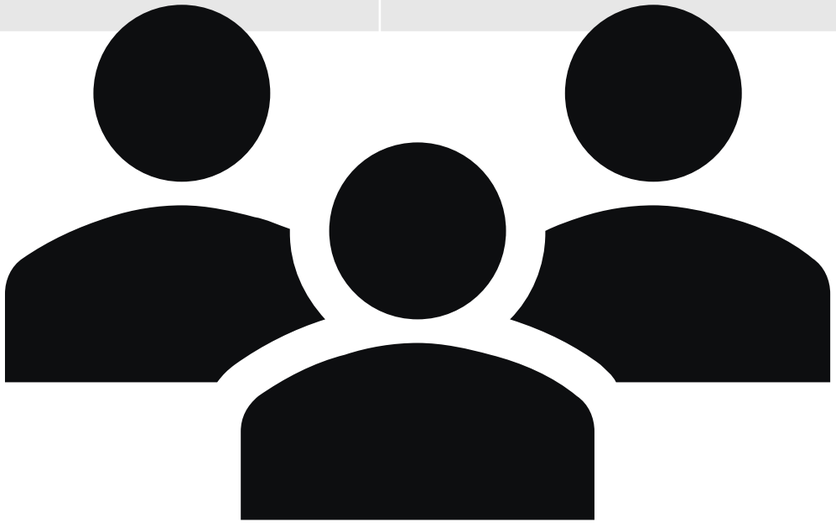


Images of the phantom array effect, sine wave (left) and rectangular wave with 10% duty cycle (right)

https://journals.sagepub.com/doi/abs/10.1177/14771535241288783

Participants

	All	Migraineur	Non-Migraineur
Number of participants	55	25	30
Median age (range)	39 yrs (22-81)	46 yrs (25-81)	37 (22-81)
Percent Age < 40 yrs	51%	56%	43%
Percent Female	53%	64%	43%



Number	Programmed Characteristics			
	Shape	Duty Cycle	Freq	% Modulation
1	Sine	N/A	120	100
2	Sine	N/A	120	85
3	Sine	N/A	120	70
4	Sine	N/A	120	55
5	Sine	N/A	120	40
6	Sine	N/A	120	25
7	Sine	N/A	120	15
8	Sine	N/A	120	5
9	Sine	N/A	400	100
10	Sine	N/A	400	85
11	Sine	N/A	400	70
12	Sine	N/A	400	55
13	Sine	N/A	400	40
14	Sine	N/A	400	25
15	Sine	N/A	400	15
16	Sine	N/A	400	5
17	Sine	N/A	800	100
18	Sine	N/A	800	85
19	Sine	N/A	800	70
20	Sine	N/A	800	55
21	Sine	N/A	800	40
22	Sine	N/A	800	25
23	Sine	N/A	800	15
24	Sine	N/A	800	5
25	Sine	N/A	1200	100
26	Sine	N/A	1200	85
27	Sine	N/A	1200	70
28	Sine	N/A	1200	55
29	Sine	N/A	1200	40
30	Sine	N/A	1200	25
31	Sine	N/A	1200	15
32	Sine	N/A	1200	5
33	Sine	N/A	2400	100
34	Sine	N/A	2400	85
35	Sine	N/A	2400	70
36	Sine	N/A	2400	55
37	Sine	N/A	2400	40
38	Sine	N/A	2400	25
39	Sine	N/A	2400	15
40	Sine	N/A	2400	5
41	Sine	N/A	4800	100
42	Sine	N/A	4800	85
43	Sine	N/A	4800	70
44	Sine	N/A	4800	55
45	Sine	N/A	4800	40
46	Sine	N/A	4800	25
47	Sine	N/A	4800	15
48	Sine	N/A	7000	100
49	Sine	N/A	10000	100
50	Sine	N/A	10000	55
51	Rect	10	120	100
52	Rect	50	120	100
53	Rect	10	120	55
54	Rect	50	120	55
55	Rect	10	400	100
56	Rect	50	400	100
57	Rect	10	400	55
58	Rect	50	400	55
59	Rect	10	800	100
60	Rect	50	800	100
61	Rect	10	800	55
62	Rect	50	800	55
63	Rect	10	1200	100
64	Rect	50	1200	100
65	Rect	10	1200	55
66	Rect	50	1200	55
67	Rect	10	2400	100
68	Rect	50	2400	100
69	Rect	10	2400	55
70	Rect	50	2400	55
71	Rect	10	4800	100
72	Rect	50	4800	100
73	Rect	10	4800	55
74	Rect	50	4800	55
75	Rect	10	10000	100
76	Rect	50	10000	100
77	Rect	10	10000	55
78	Rect	50	10000	55
79	Complex			
80	Complex			
81	Complex			
82	Complex			
83	Complex			
84	Complex			
85	DC			

85 unique TLM waveforms shown to participants (nominal values):

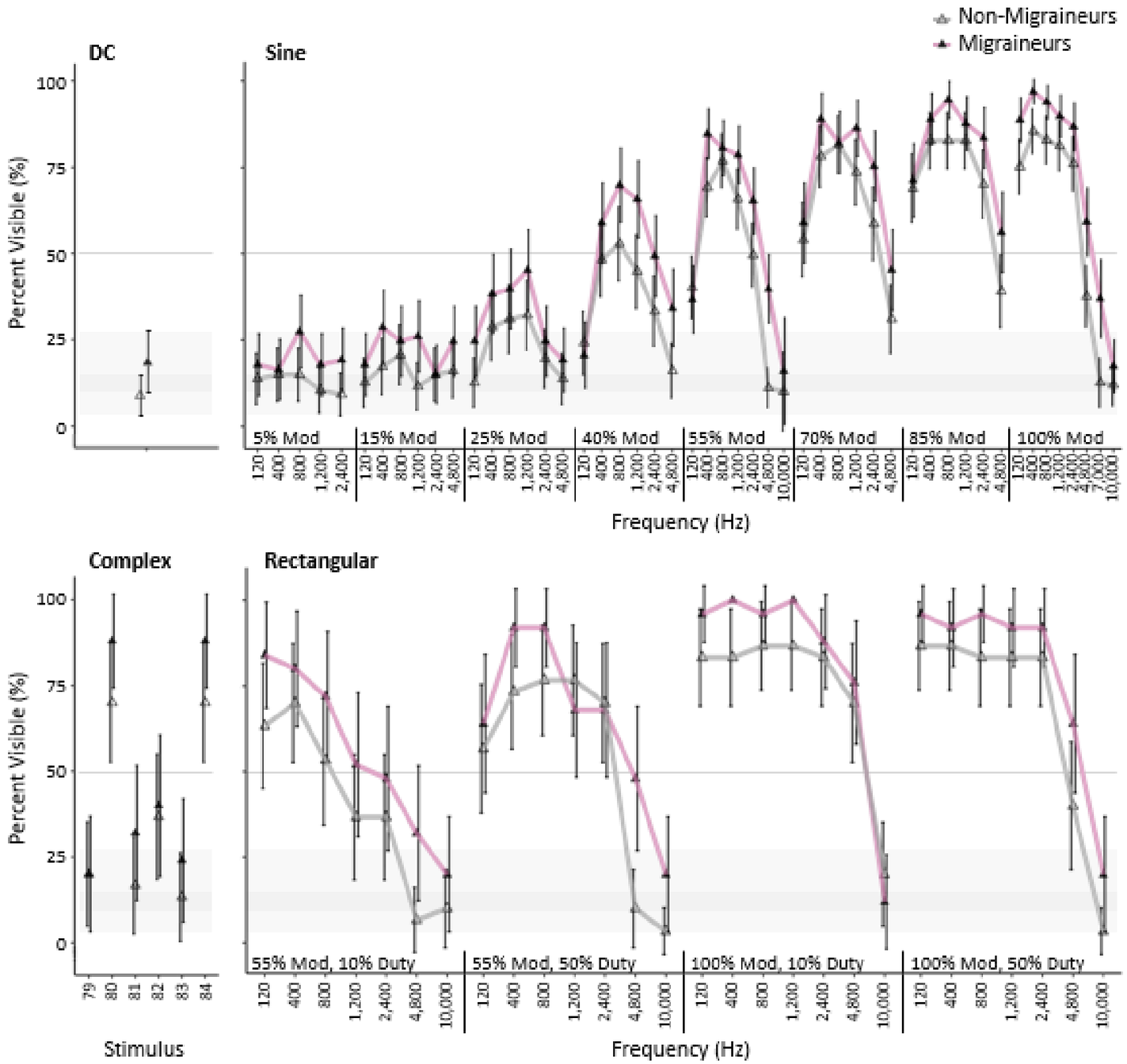
- Sine 120 Hz – 10,000 Hz
  5% to 100% modulation
- Rect. 120 Hz – 10,000 Hz
  10% and 50% duty cycle
  55% and 100% modulation
- Complex waves to test Fourier summation
- DC waves to test for subject response reliability

Most waveforms shown multiple times, with randomization.
Subjects responded Y or N to PAE visibility.
Subset of trials also asked for 0 to 8 annoyance rating.

Key Results

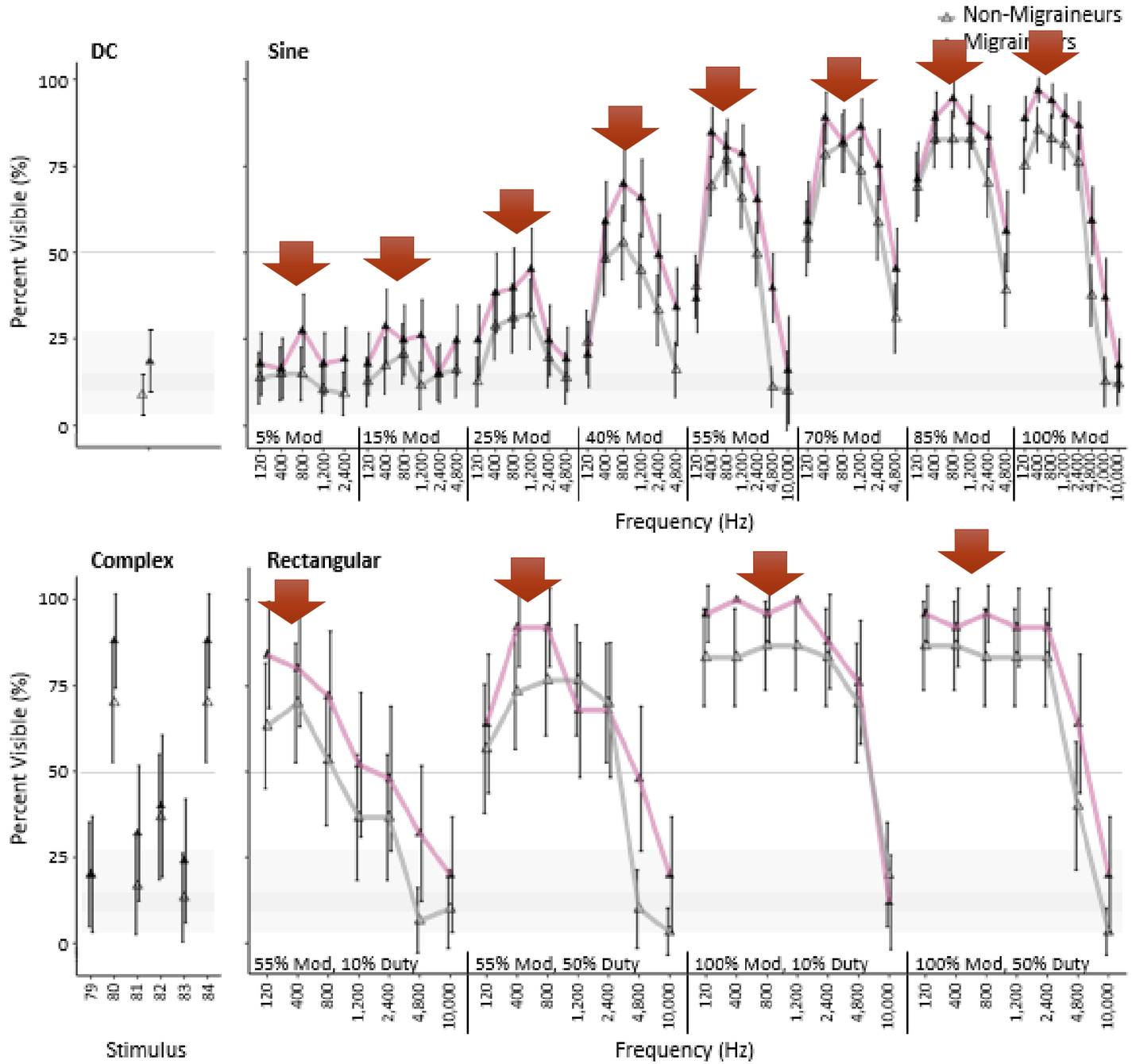
Migraineurs are more likely to see the PAE

(pink lines almost always above gray)



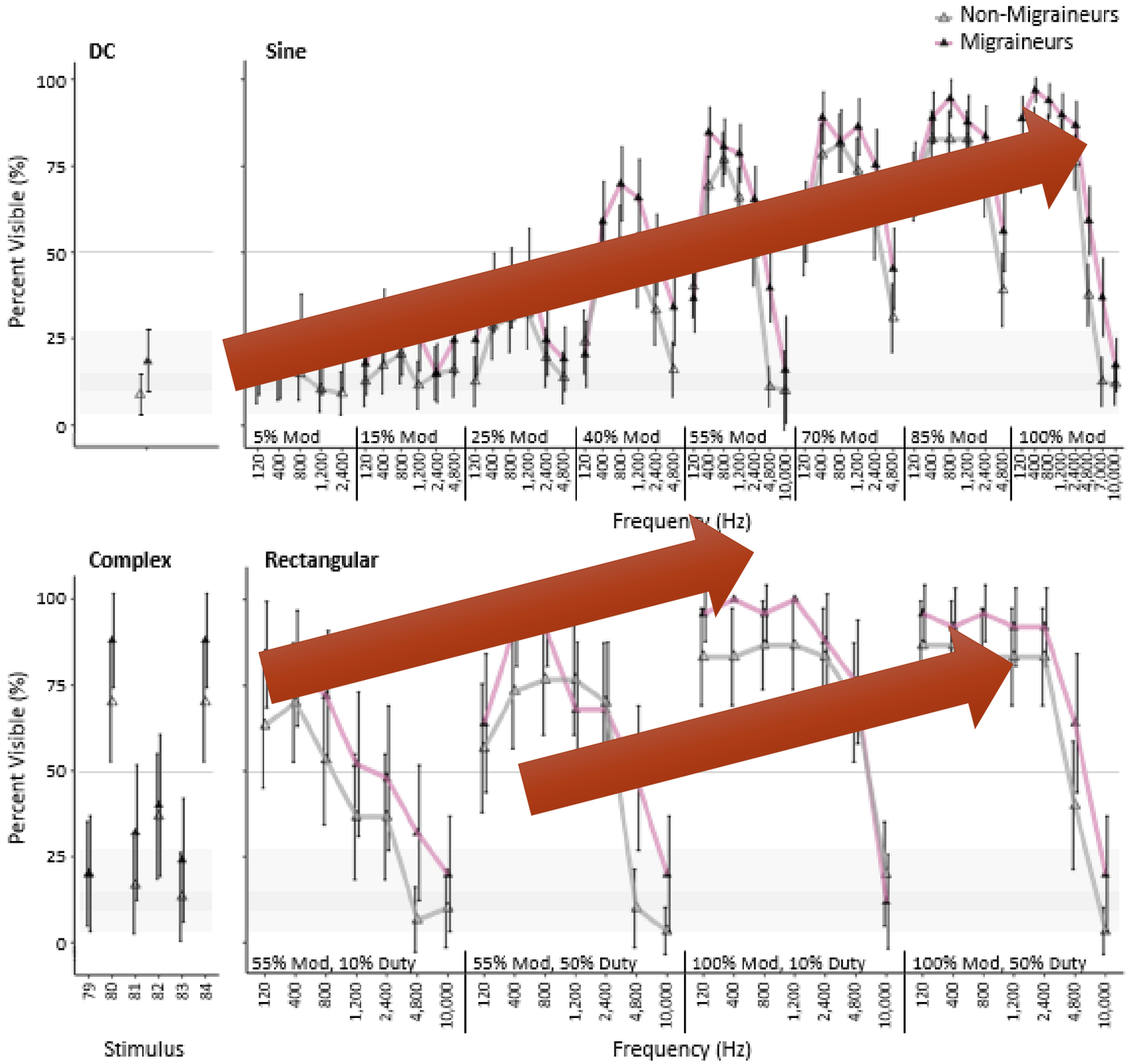
Key Results

Peak visibility between 400 Hz and 1,200 Hz



Key Results

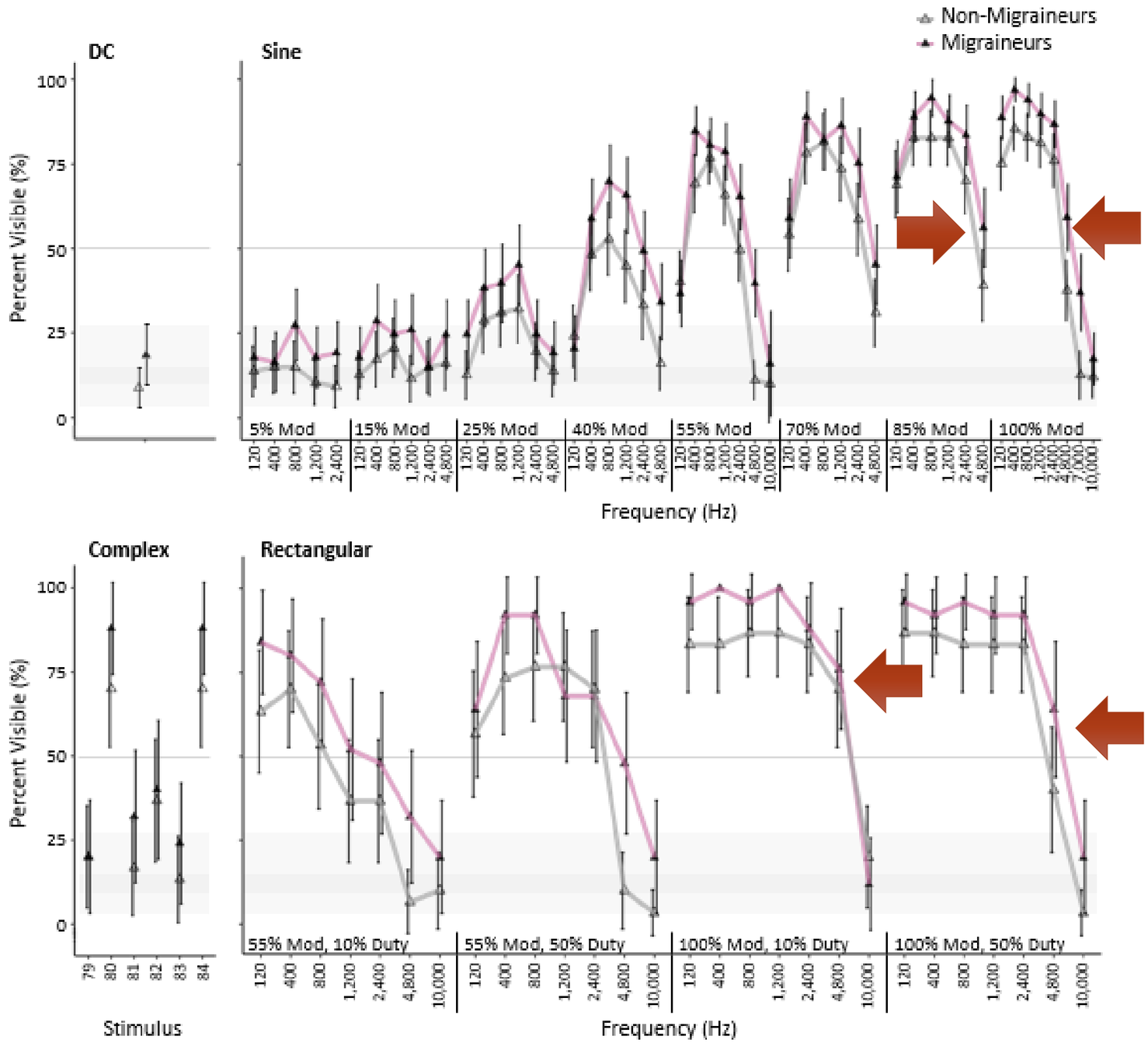
More modulation = more visibility



Key Results

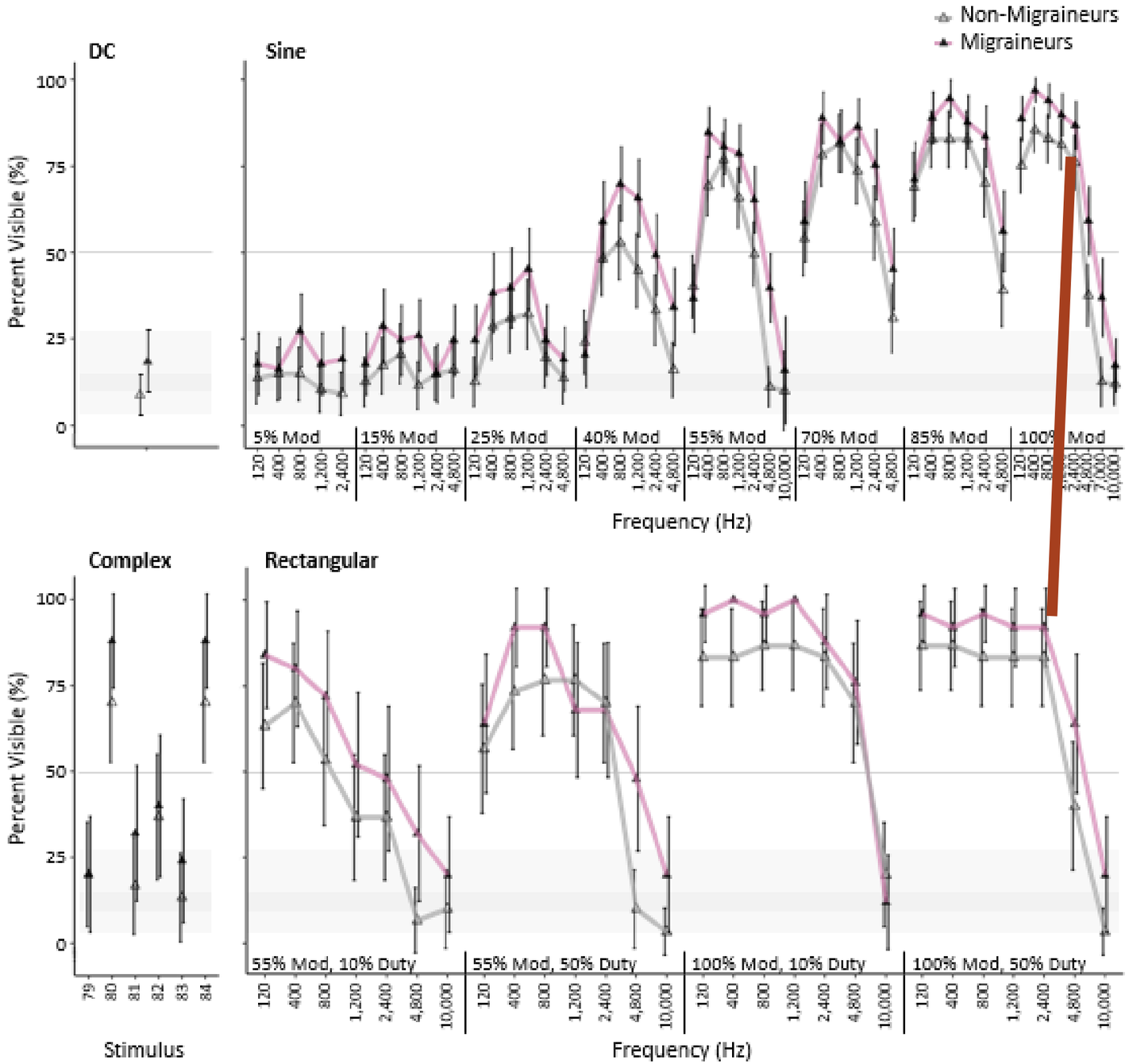
High modulation visible to a majority at 4,800 Hz

73% of all participants saw rectangular waves (above threshold) at 4,800 Hz, 100% mod, 10% duty cycle



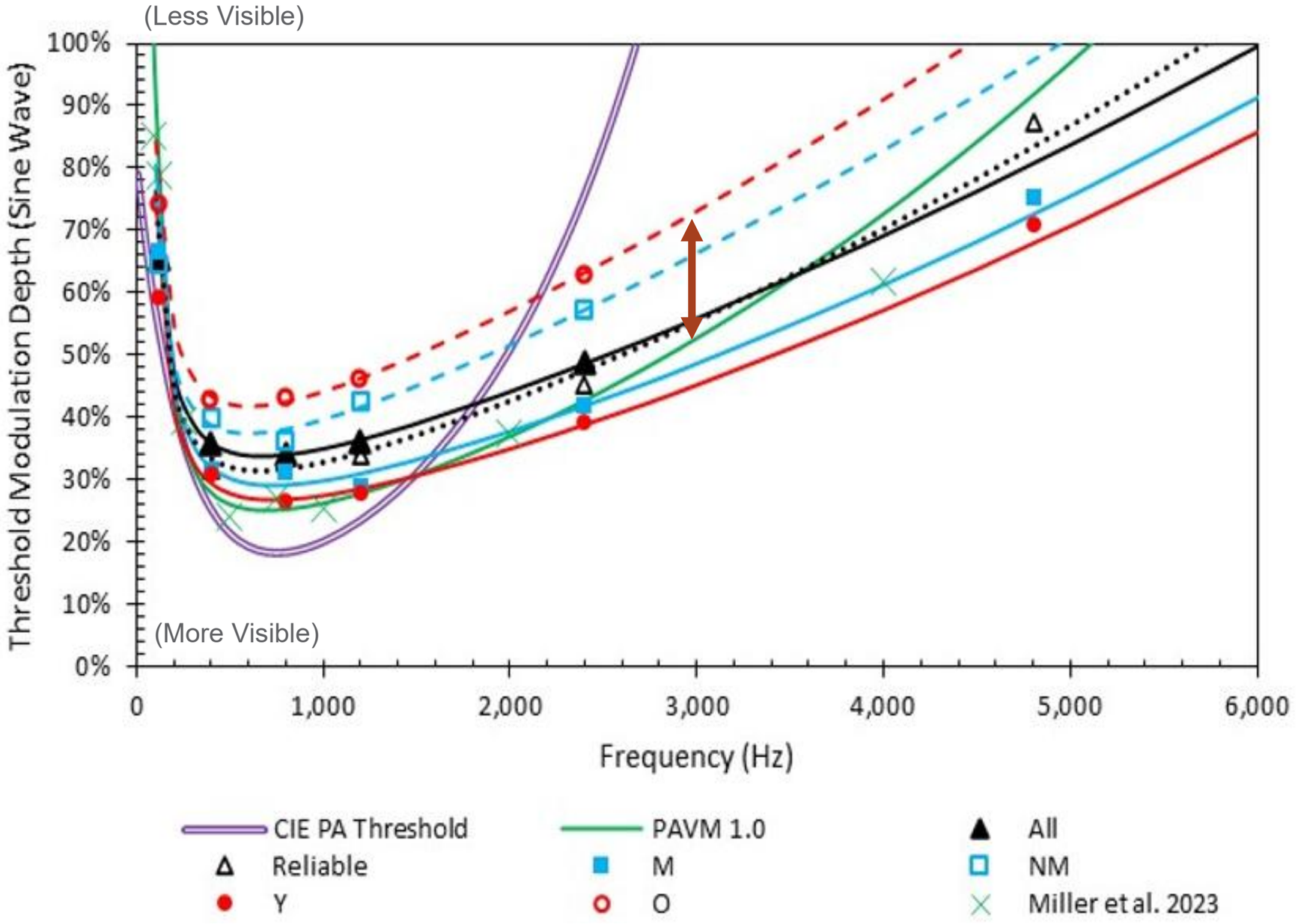
Key Results

Rectangular (i.e., PWM) more visible than sinusoidal



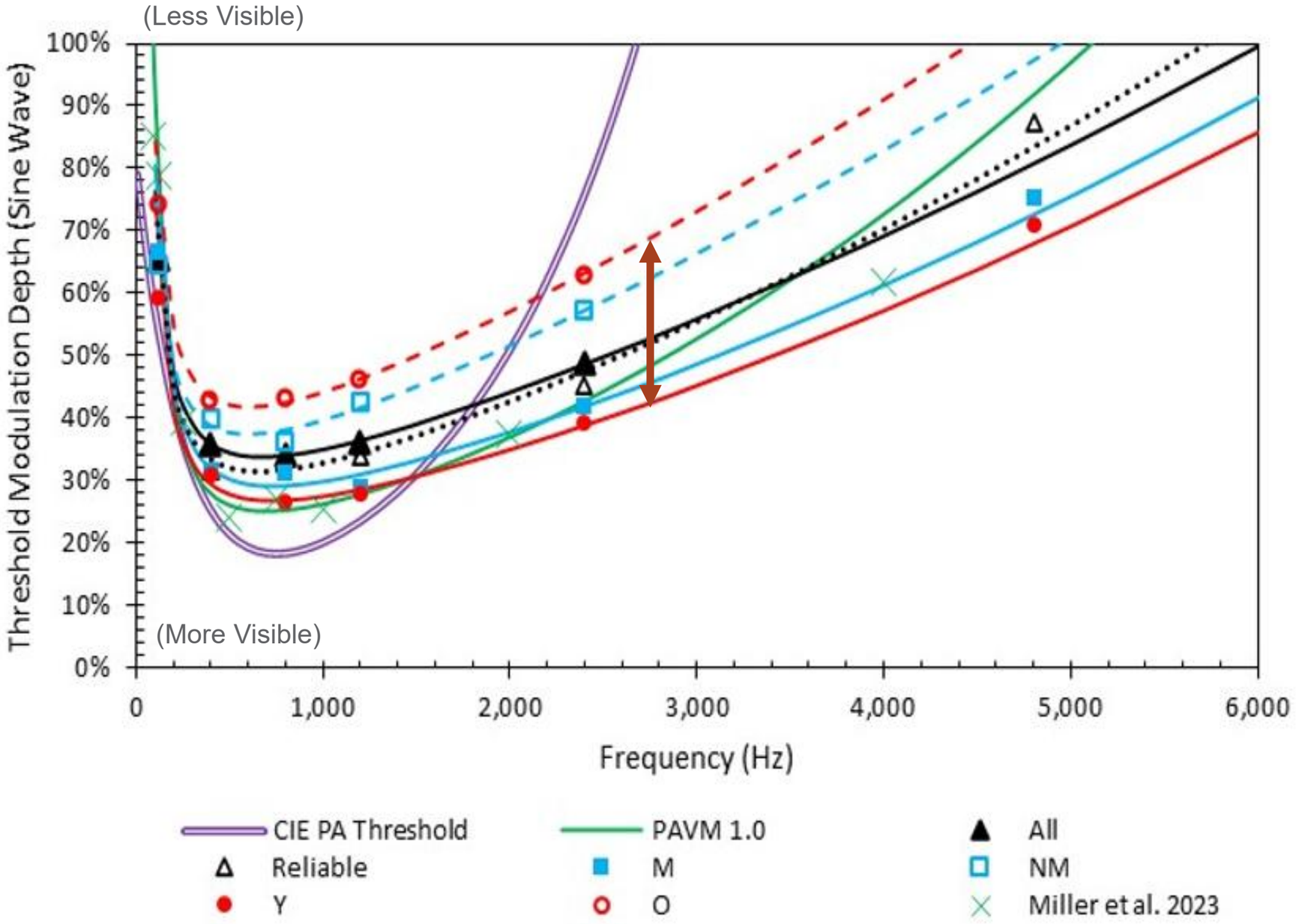
Key Results

Migraineurs more sensitive than non-migraineurs



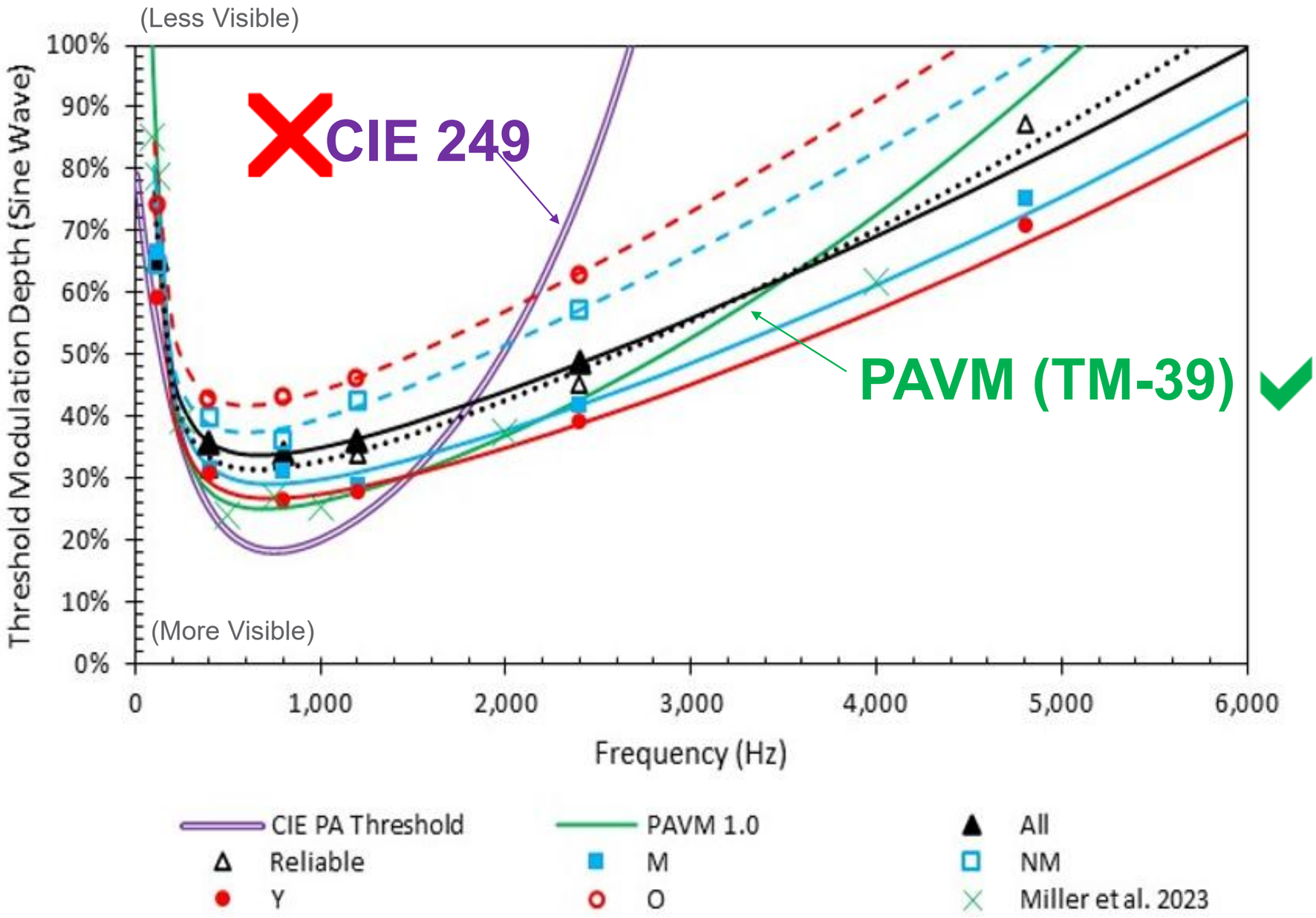
Key Results

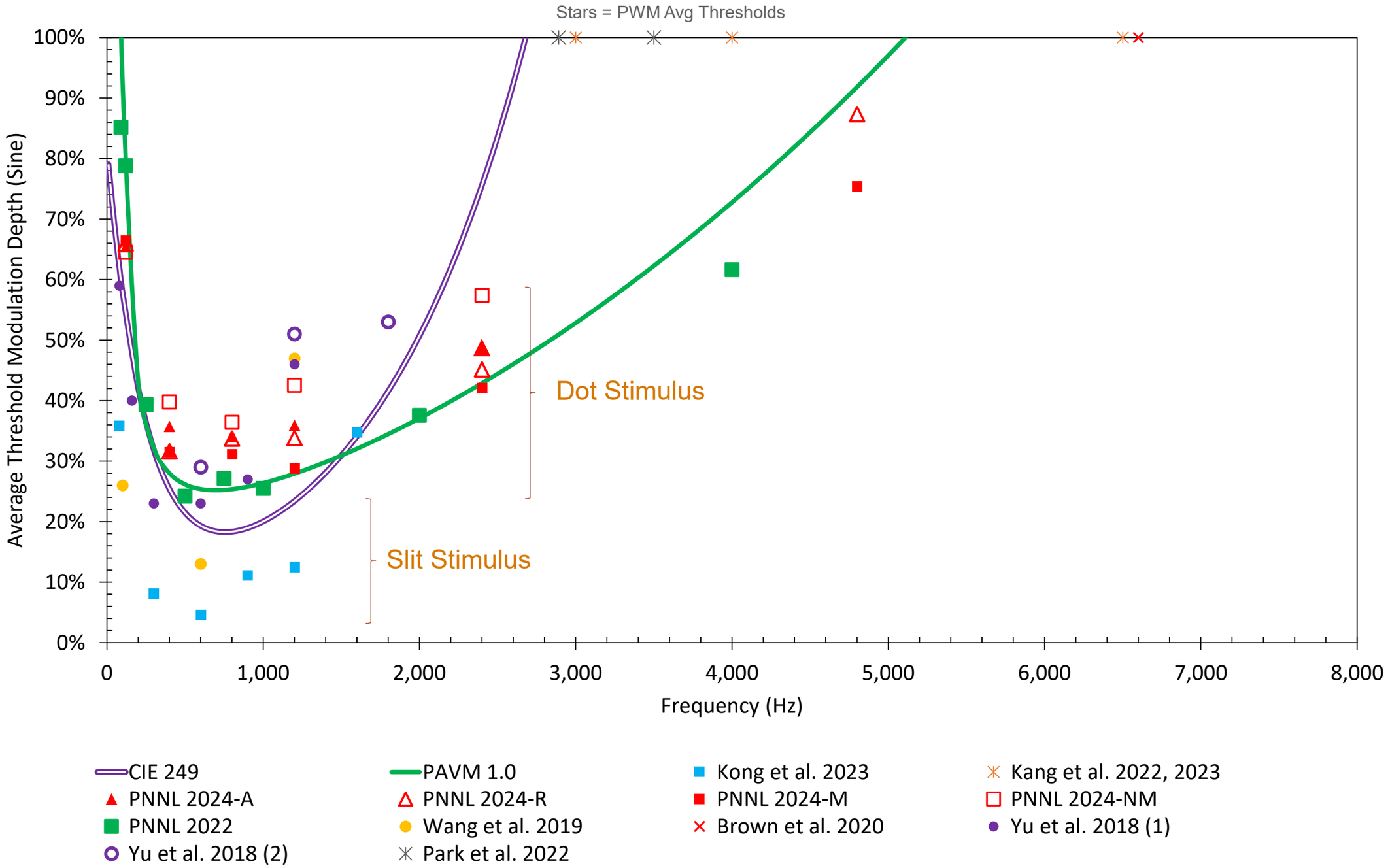
Younger people had higher sensitivity



Key Results

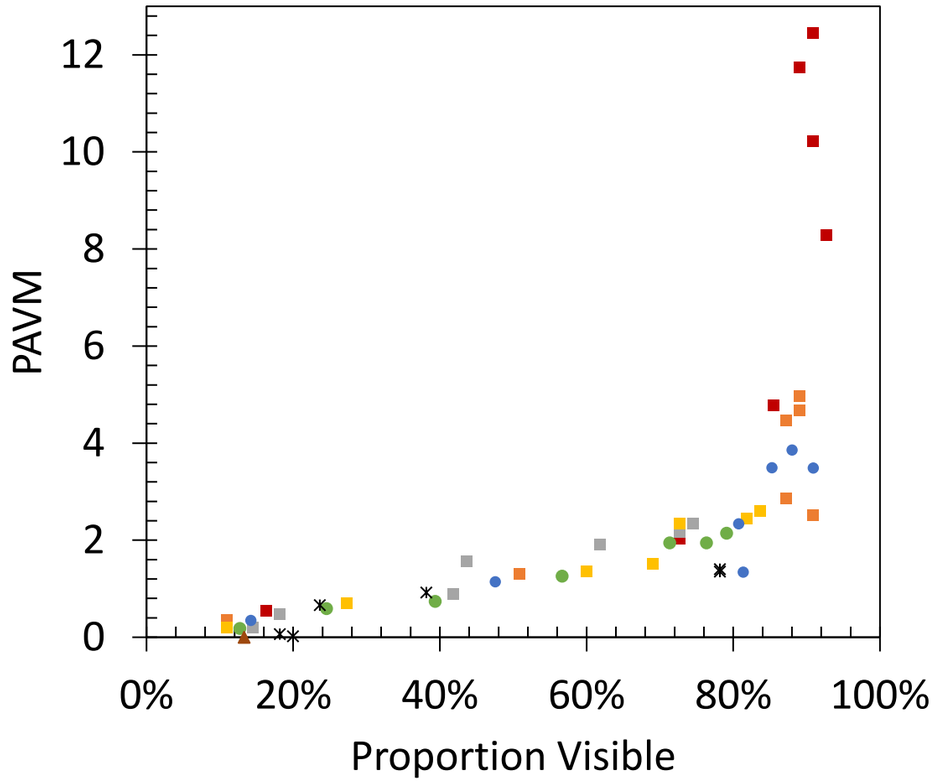
PAVM works!

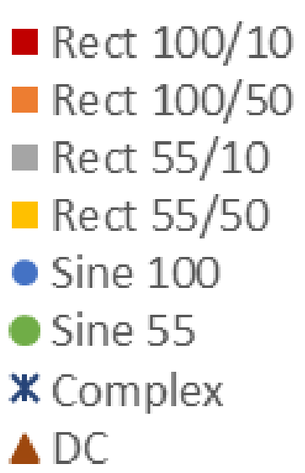


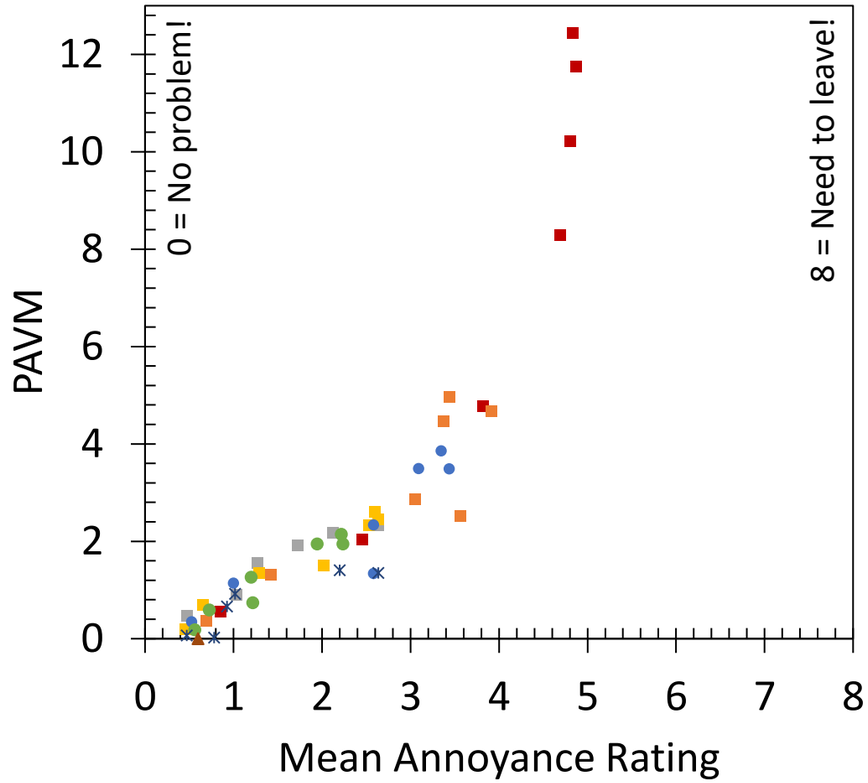

Stars = PWM Avg Thresholds
Average Threshold Modulation Depth (Sine)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
Frequency (Hz)
Dot Stimulus
Slit Stimulus
CIE 249
PAVM 1.0
Kong et al. 2023
Kang et al. 2022, 2023
PNNL 2024-A
PNNL 2024-R
PNNL 2024-M
PNNL 2024-NM
PNNL 2022
Wang et al. 2019
Brown et al. 2020
Yu et al. 2018 (1)
Yu et al. 2018 (2)
Park et al. 2022

Key Results

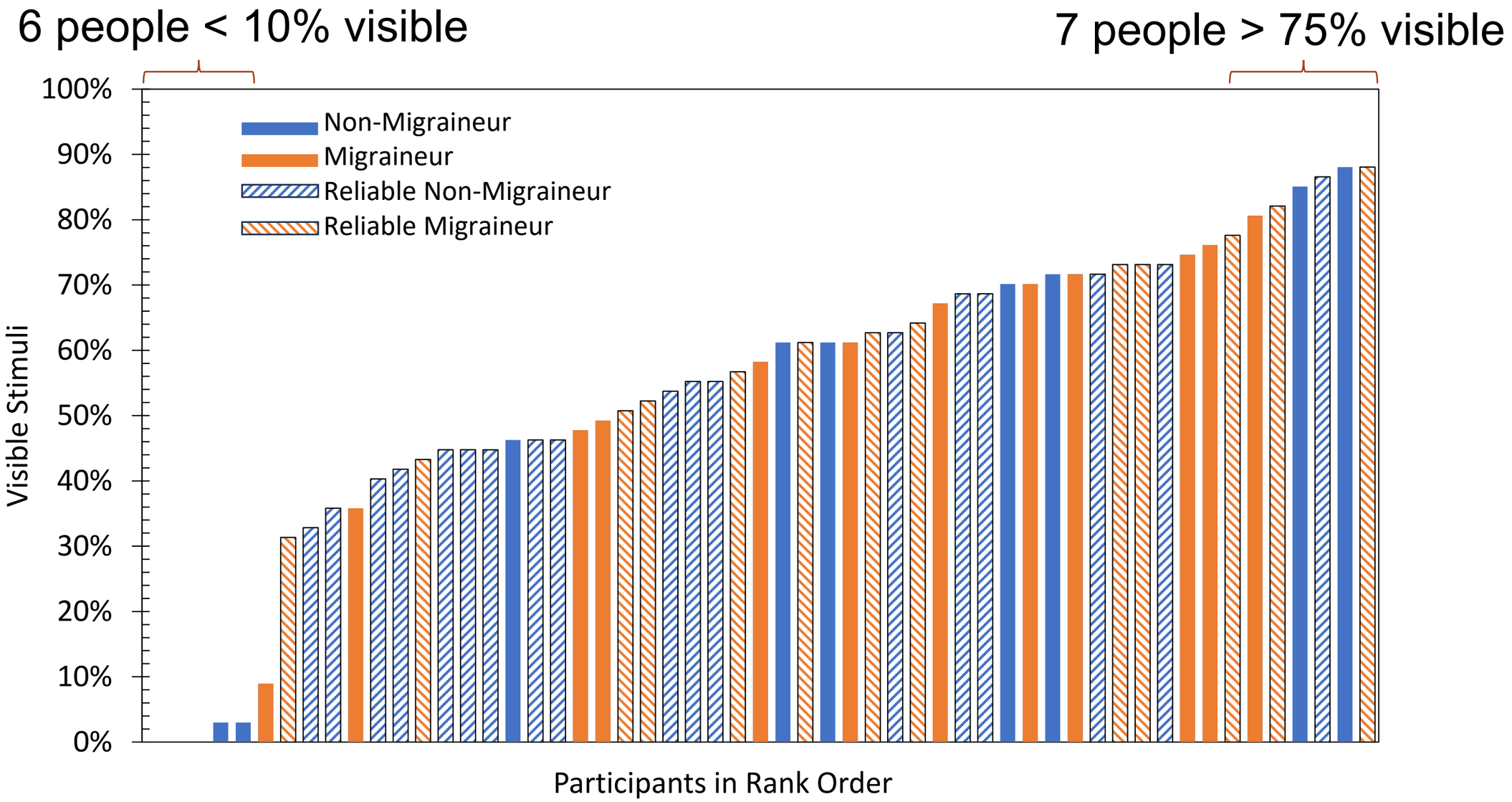
- PAVM predicts visibility and annoyance
- Linear in region of interest
- For 10% Duty cycle 100% modulation, 20% to 33% (depending on frequency) rated an 8







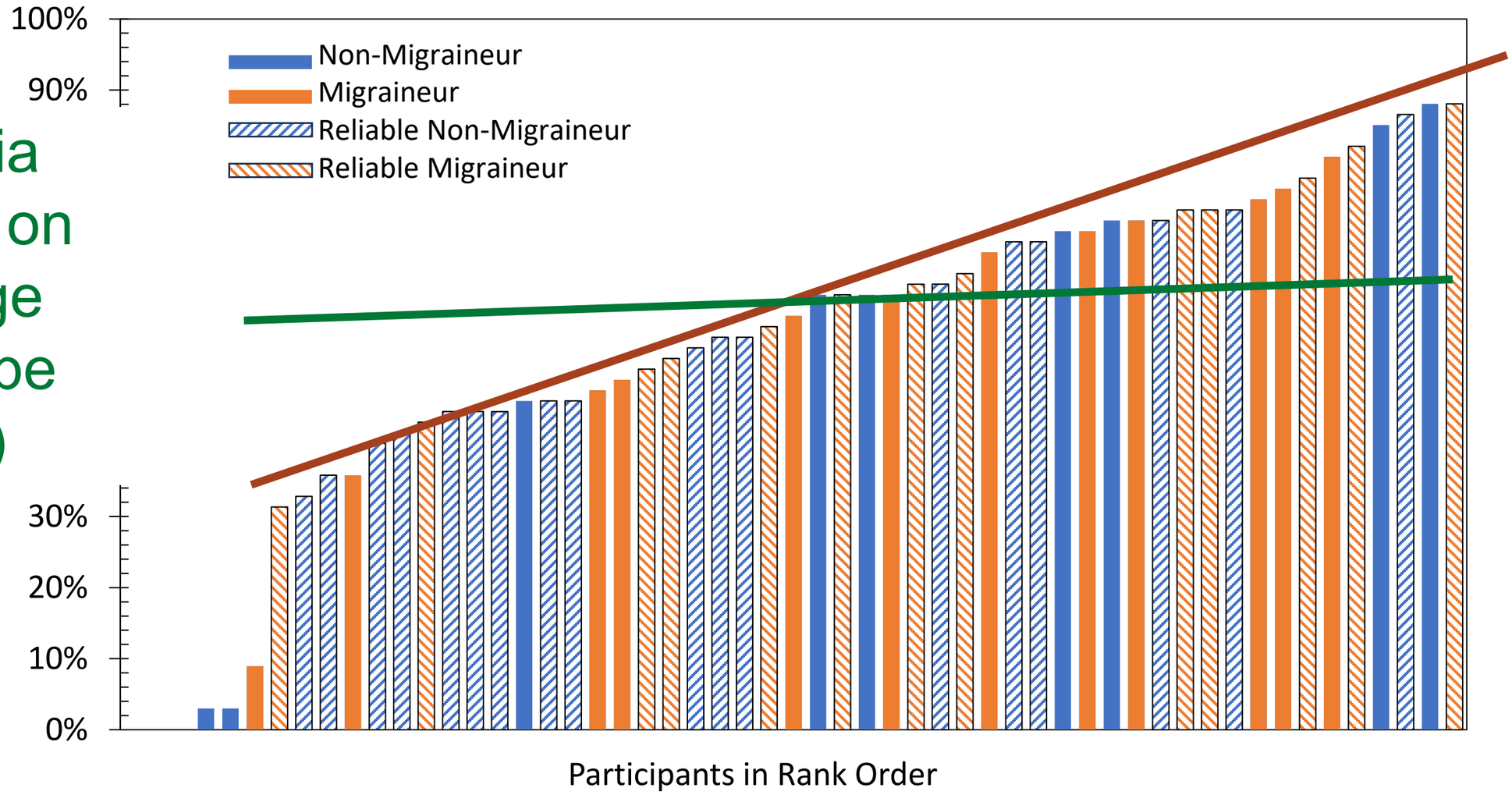
Key Results


6 people < 10% visible
7 people > 75% visible
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Visible Stimuli
Non-Migraineur
Migraineur
Reliable Non-Migraineur
Reliable Migraineur
Participants in Rank Order

Key Results

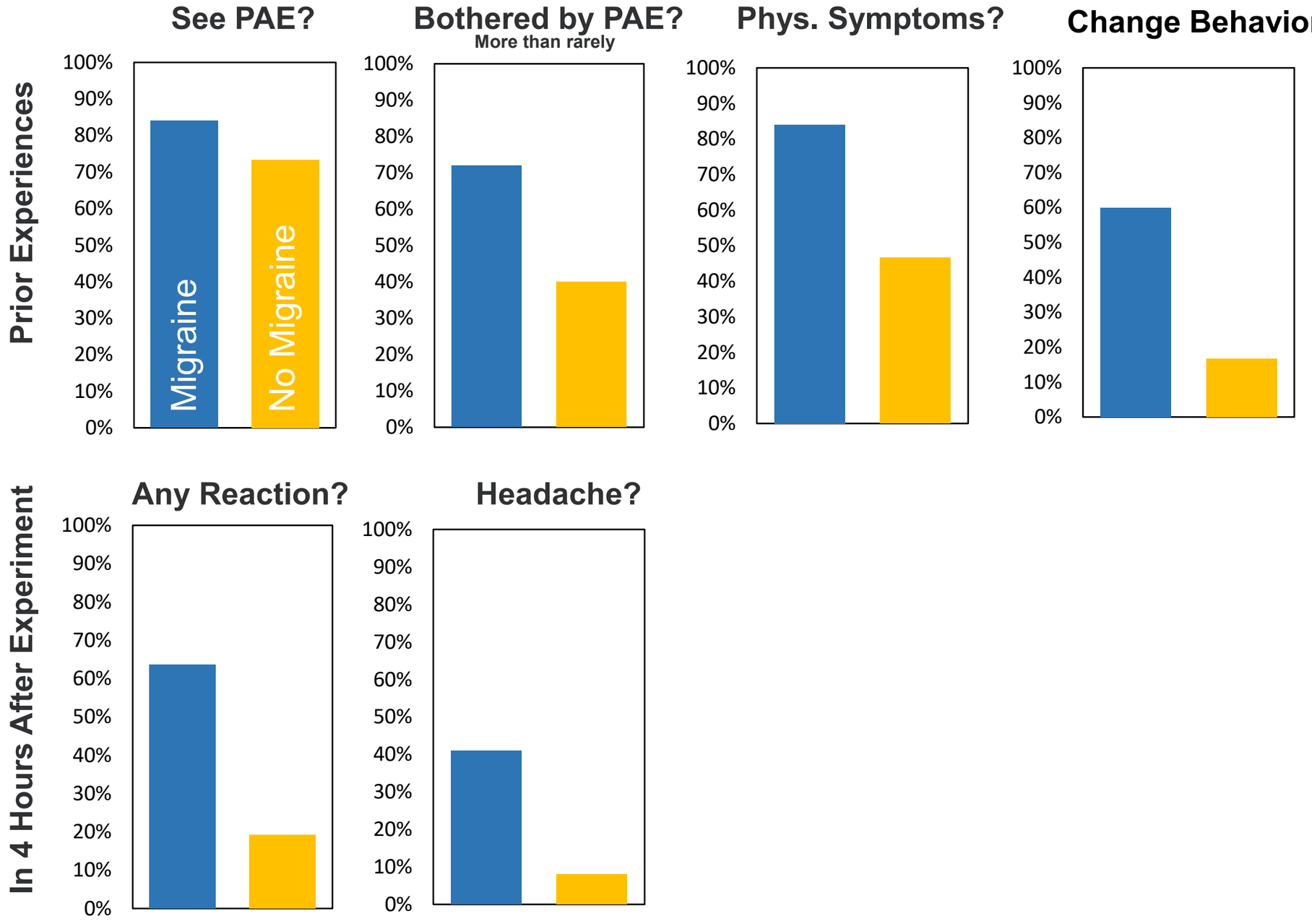
Criteria based on average not very useful!

(Criteria based on average might be useful)



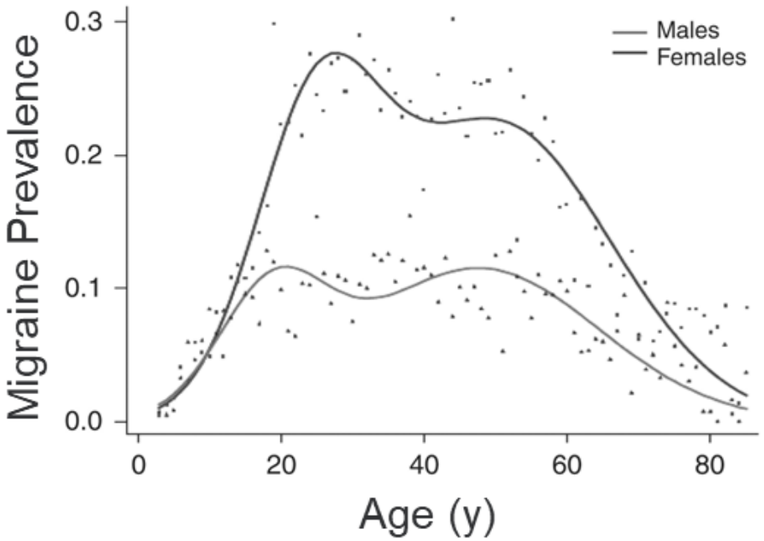
Substantial level of consequence, but not equal for all people.

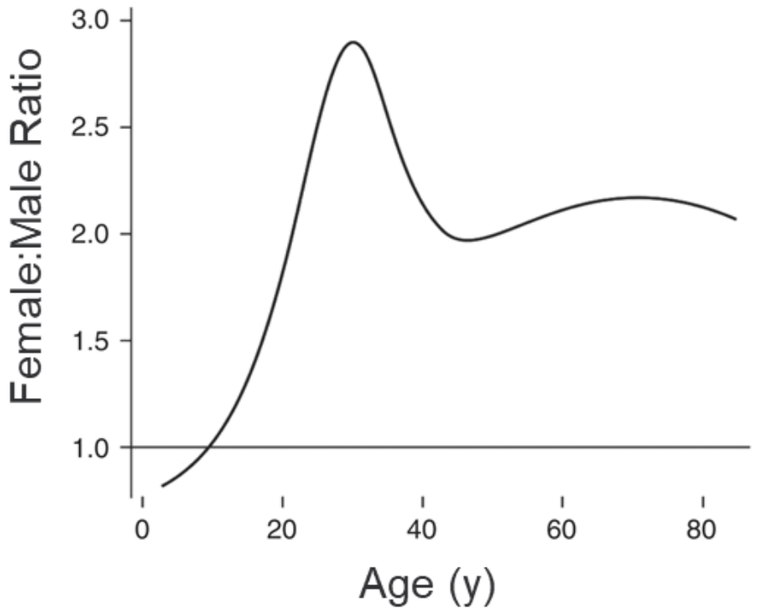
It’s not just visible!



Migraines:

- ~16% of adults worldwide
- Peak in 30s
- 2:1 to 3:1 ratio of women to men
- Nearly 30% of women in their 30s!
- Second leading cause of time with disability worldwide
- Links to both lighting and IAQ
- Past evidence suggests effect of TLM





https://pubmed.ncbi.nlm.nih.gov/20713557/

ANSI/IES TM-39: *Quantification and Specification of Flicker*

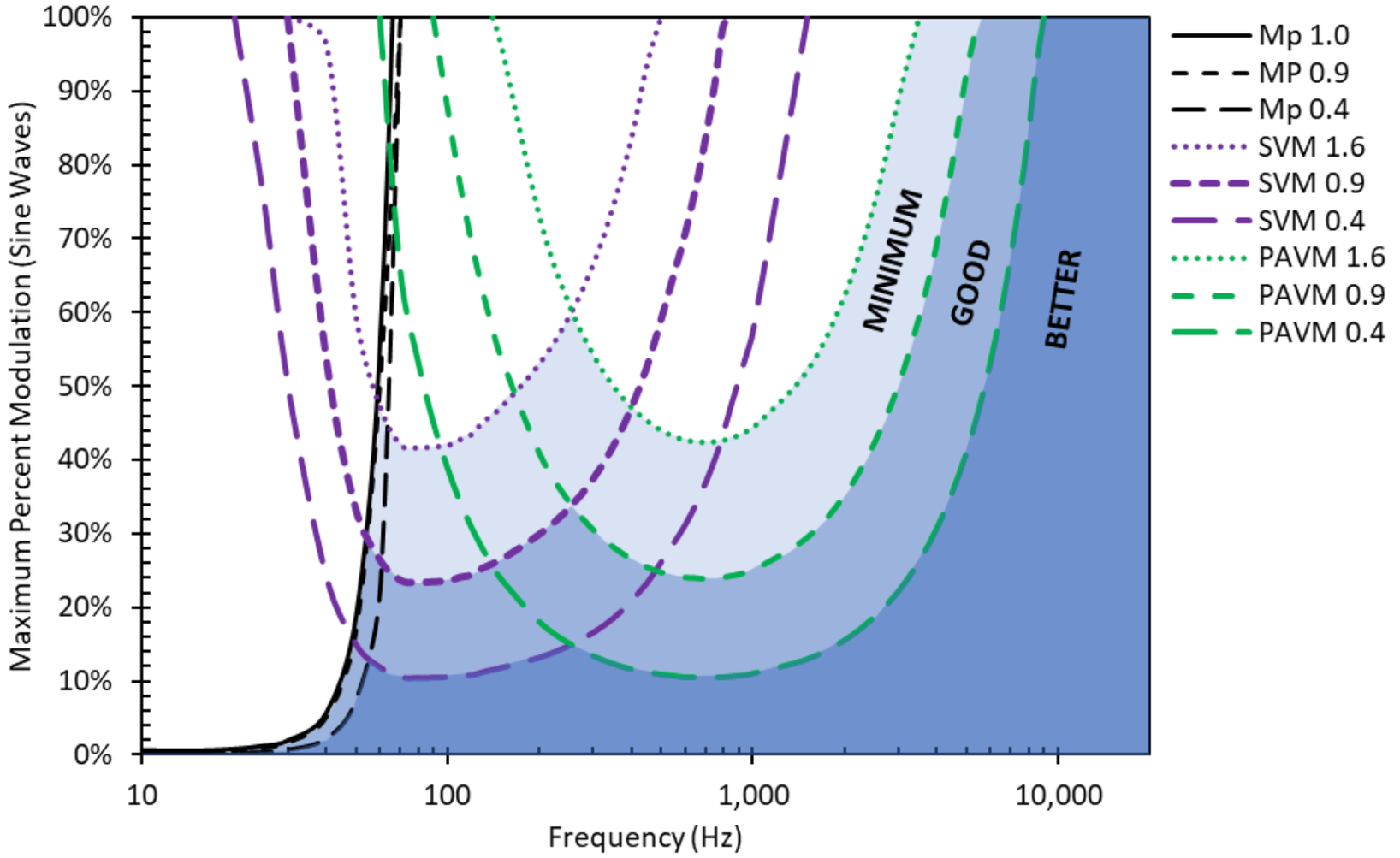
- Document being finalized after public review
- Defines terms, summarizes research, describes metrics:
  - ❖ Flicker Perception Metric (M_P)
  - ❖ Stroboscopic Visibility Measure (SVM)
  - ❖ Phantom Array Visibility Measure (PAVM)
- Provides provisional Minimum – Good – Better guidelines based on TLM effect, target metric values, and population sensitivity

ANSI/IES TM-39: *Quantification and Specification of Flicker*

- Contains provisional guidelines for interior applications
- 3 metrics; 3 target values; 3 quality levels

	MINIMUM	GOOD	BETTER
Metric Method			
Direct Flicker	$M_p \leq 1.0$	$M_p \leq 0.9$	$M_p \leq 0.4$ For 6 Hz ≤ f ≤ 30 Hz, modulation ≤ 0.1%
Stroboscopic Effect	SVM ≤ 1.6	SVM ≤ 0.9	SVM ≤ 0.4
Phantom Array Effect	PAVM ≤ 1.6	PAVM ≤ 0.9	PAVM ≤ 0.4
Alternate Frequency Method			$f \geq 10{,}000$ Hz for sinusoidal waveforms $f \geq 20{,}000$ Hz all other or DC Waveform

IES TM-39 guidelines based on modulation for M_P, SVM, PAVM



IES TM-39 criteria and experiment results