Retinal Motion and Visual Sensitivity During Smooth Pursuit

Bin Yang
07.14.2020

OUTLINE

- Background
  - Eye Movement Patterns During Smooth Pursuit
  - Visual Sensitivity during Smooth Pursuit
    - Retinal Effect
    - Non-retinal Effect
  - Summary & Scientific Questions
- Preliminary Experiments & Data
  - Characterize Pursuit EMs: pursuit gain, pos dist, vel dist
  - Factor Analysis
- Brain Storming

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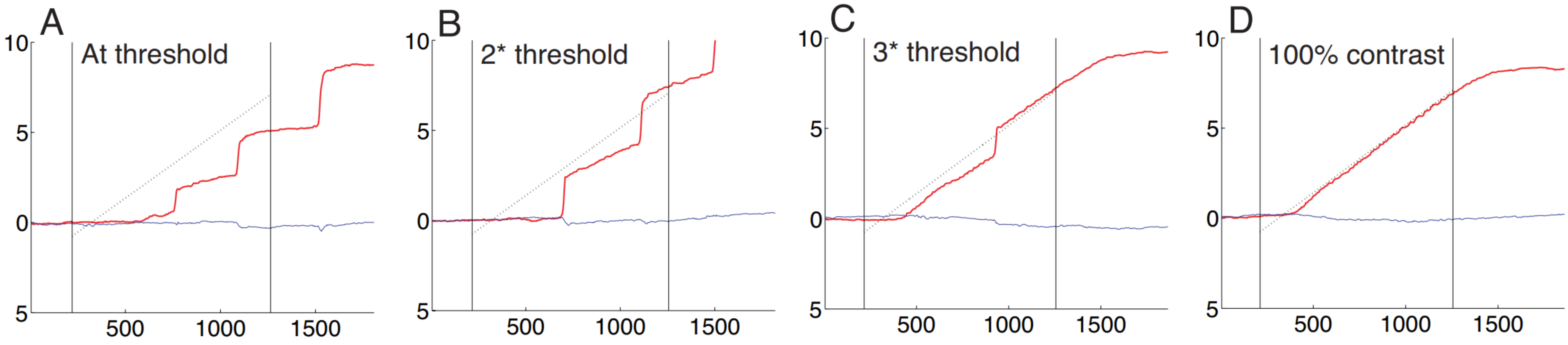
Background: Eye Movement Patterns

Smooth Pursuit

- ➢ Smooth pursuit allows the eyes to keep a moving target on the fovea
- ➢ Eye velocity is often slower than that of the target (see Lisberger et al, 1987 for review)
    - ▪ Result in retinal image slip and catch-up saccades
    - ▪ Thought to be caused by errors in tracking the moving target
- ▪ Defined as the smooth component, excluding interleaved saccades (Lisberger et al, 1987)

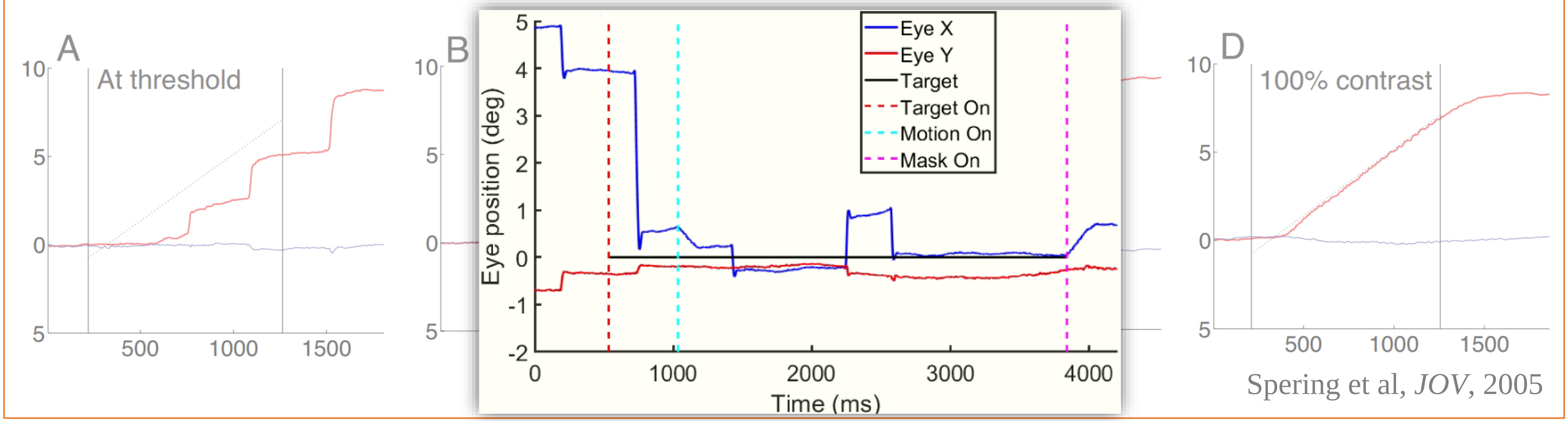


Spering et al, *JOV*, 2005

Background: Eye Movement Patterns

Smooth Pursuit

- Smooth pursuit allows the eyes to keep a moving target on the fovea
- Eye velocity is often slower than that of the target (see Lisberger et al, 1987 for review)
  - Result in retinal image slip and catch-up saccades
  - Thought to be caused by errors in tracking the moving target
- However, there are still retinal motion and saccades even when pursuit very accurate.

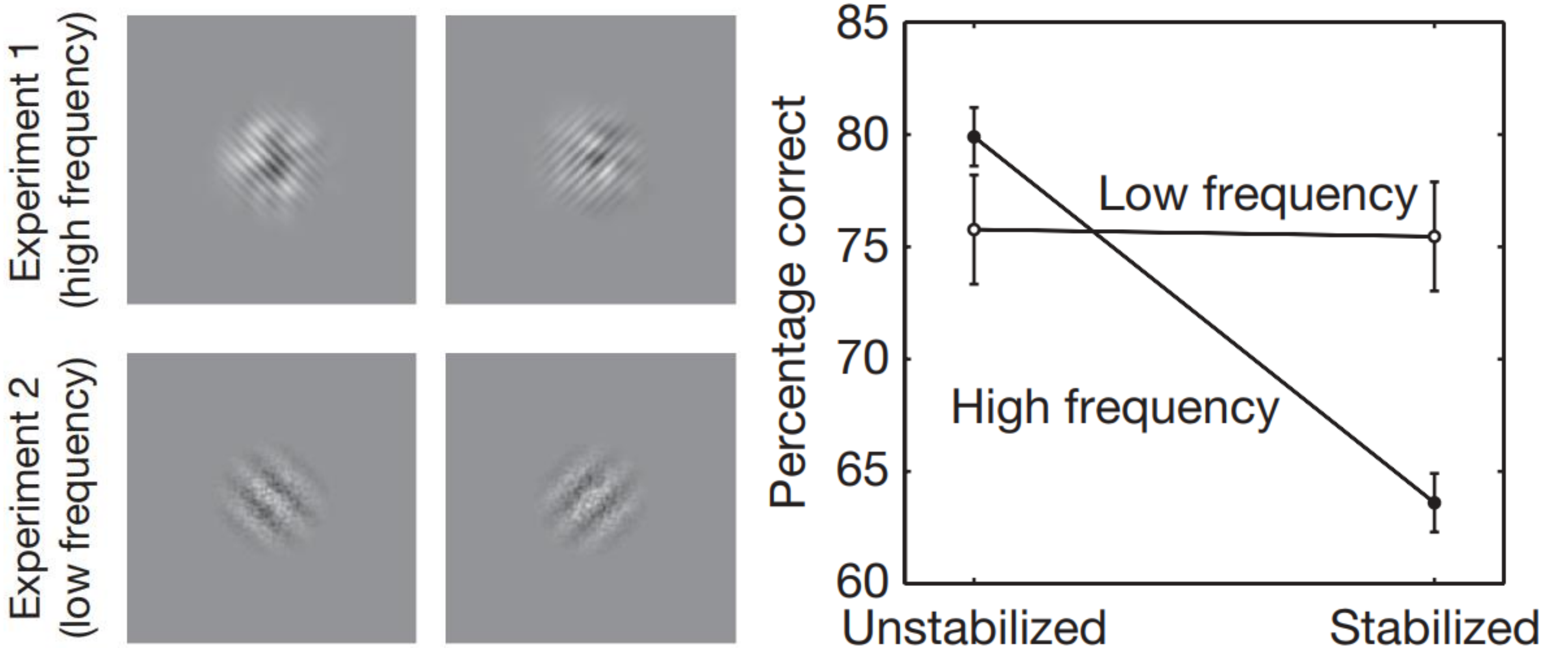


Spering et al, *JOV*, 2005

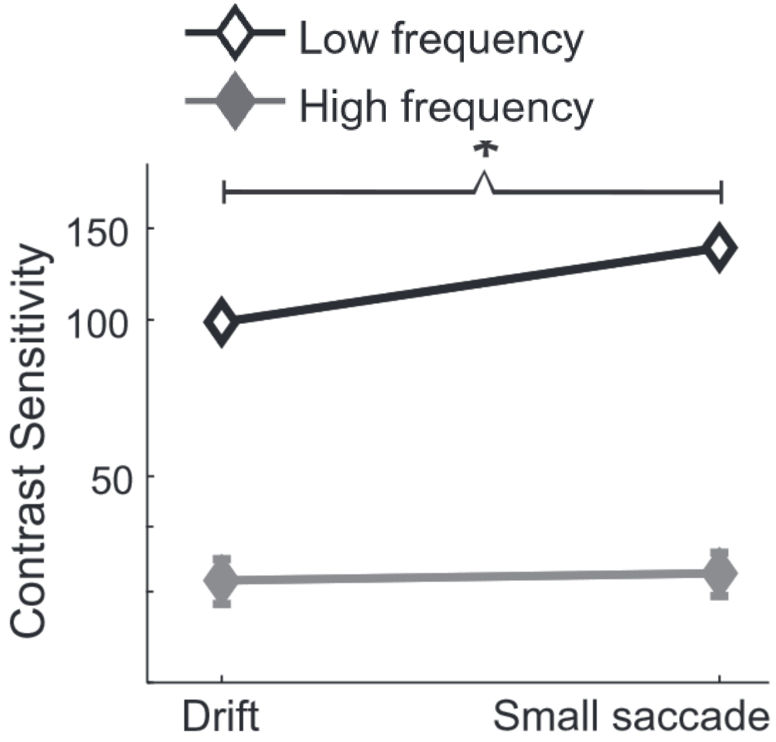
Background: Eye Movement Patterns

Retinal Instability

- ➢ Retinal instability exists even when pursuit very accurate, resulting in retinal motion
- ➢ Retinal motion from fixation and saccades enhance visual contrast sensitivities
- ➢ **How does retinal instability during accurate pursuit affect visual sensitivity?**



Rucci et al, Nature, 2007



Mostofi et al, Vision Research, 2016

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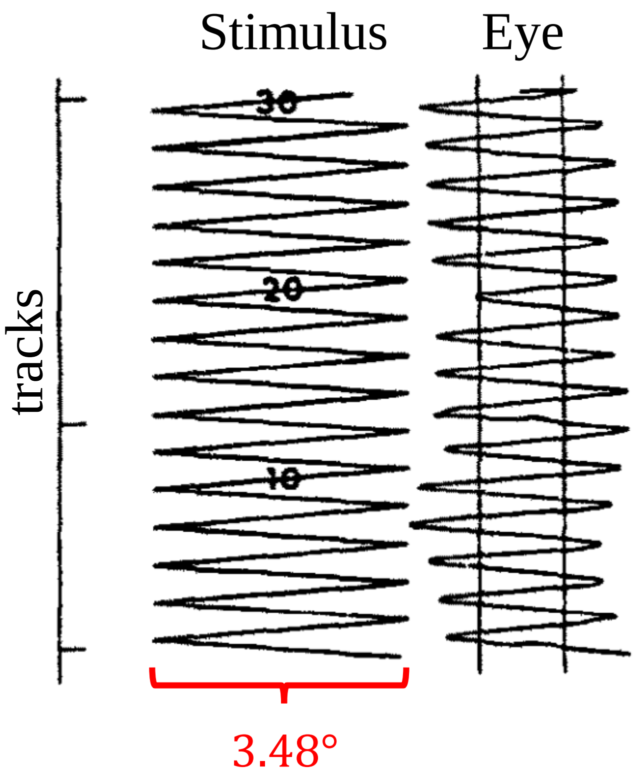
Background: Visual Sensitivity

Retinal Effect

➢ The higher the retinal velocity, the lower the sensitivity to 5.14 cpd.

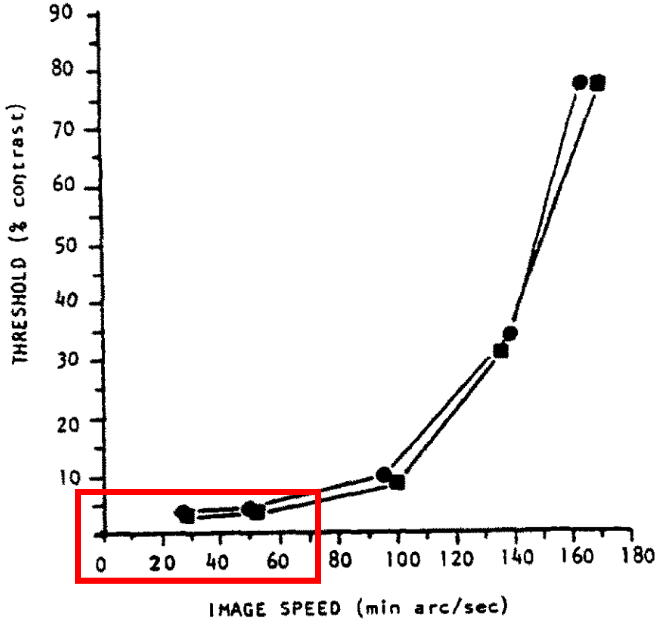


Grating and Target Move Together

Table 2. Mean pattern threshold contrast (%) and retinal image speed of subjects *RS* and *EK* during smooth pursuit of targets moving at several speeds (*stimulus*)

	Stimulus (min arc/sec)	%	*N*	Image (min arc/sec)	*N*
Subject *RS*	0	2.4 (0.6)	18		
	51.1	3.1 (0.3)	10	5.4 (3.4)	52
	141.5	3.5 (0.4)	10	8.6 (6.9)	77
	232.4	3.6 (0.4)	10	21.6 (16.0)	115
	322.5	3.8 (0.2)	10	38.1 (23.7)	139
	412.4	4.6 (0.6)	10	63.3 (36.4)	159
Subject *EK*	0	3.9 (1.2)	21		
	49.5	3.8 (1.3)	12	4.7 (3.2)	47
	138.1	3.2 (0.8)	12	15.8 (11.2)	83
	226.0	3.7 (1.1)	12	27.0 (18.0)	79
	311.6	5.2 (1.8)	12	56.0 (36.7)	85
	402.4	5.5 (1.4)	12	76.7 (46.0)	97

Fixation while Grating Move



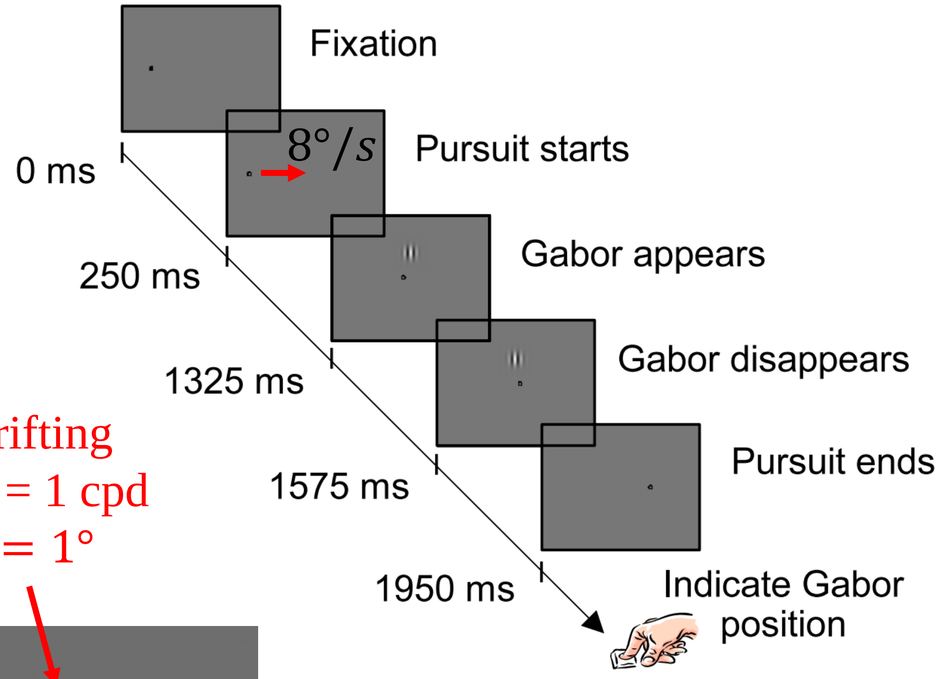
- 2-point pursuit target
- Grating: 5.14 cpd, 1.36° × 1.36°

Murphy, *Vision Research*, 1978

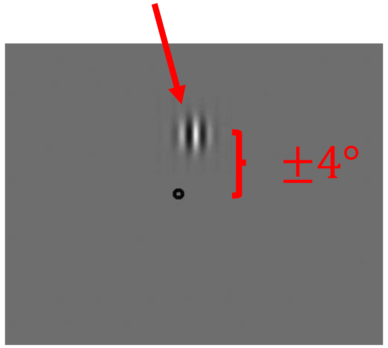
Background: Visual Sensitivity

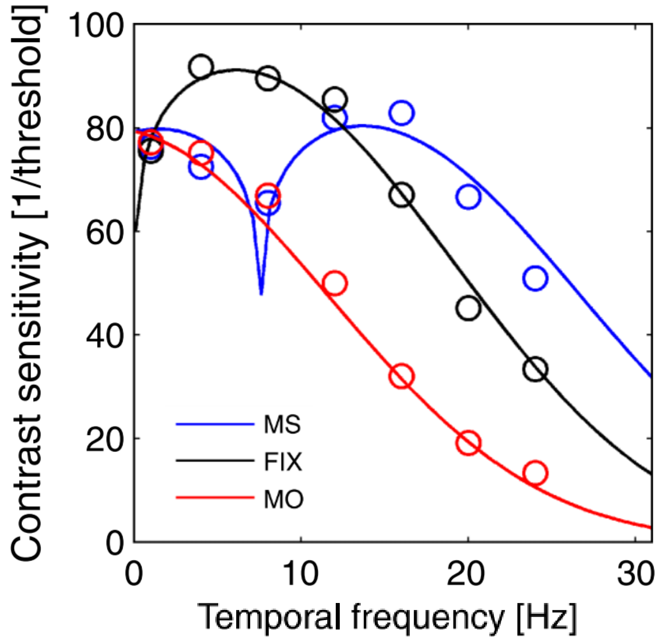
Retinal Effect

- Smooth pursuit shifts the temporal sensitivity function as a function of retinal velocity.



- Drifting
- sf = 1 cpd
- $\sigma = 1°$





- MS: motion at same direction of pursuit
- MO: motion at opposite direction of pursuit

Schütz et al, *JOV*, 2007

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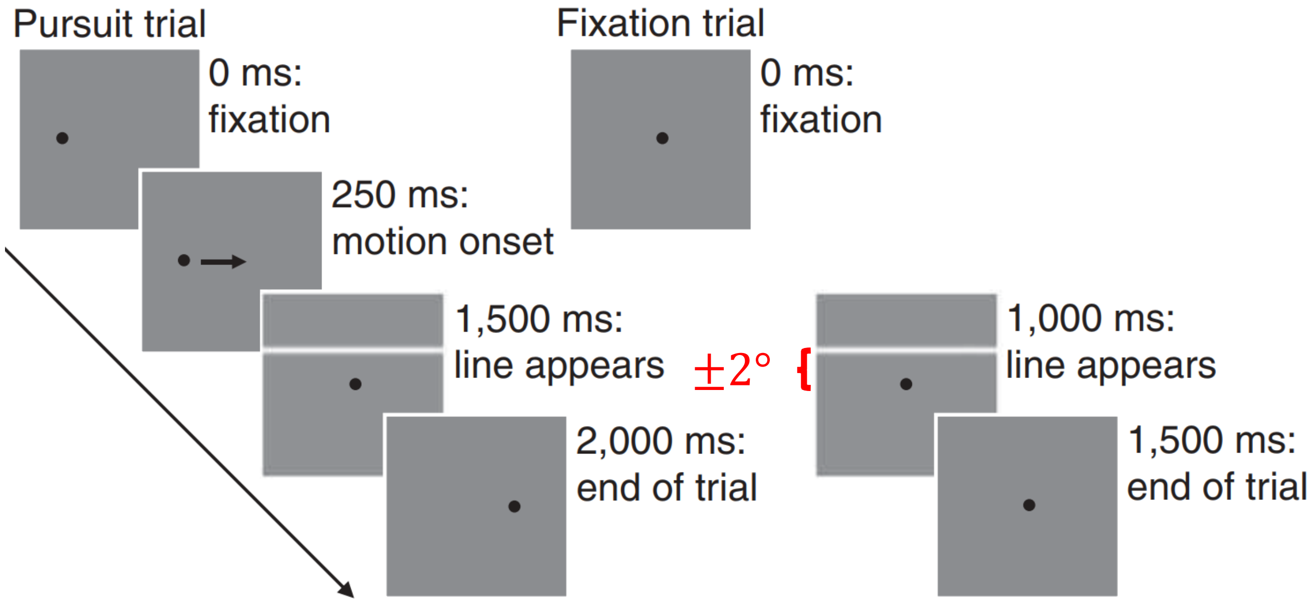
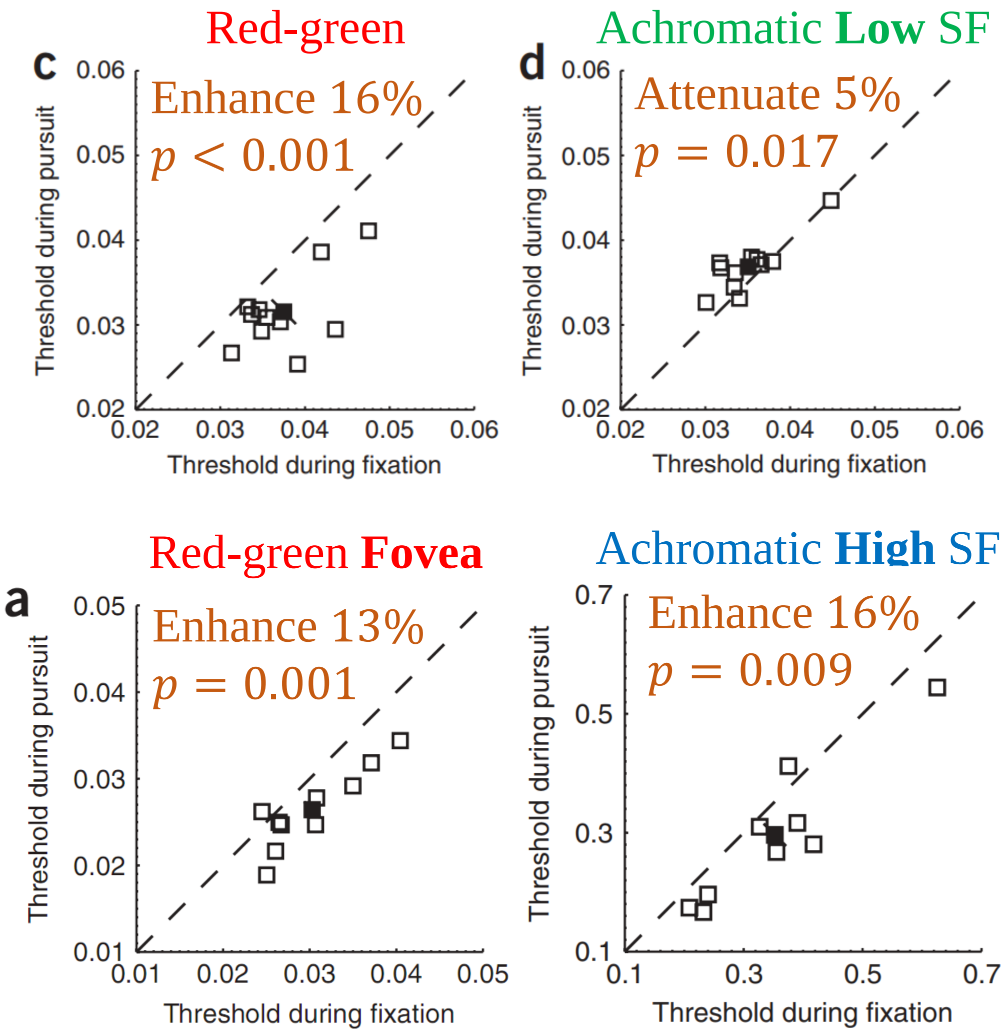
Background: Visual Sensitivity

Non-Retinal Effect

- Enhance color & achromatic high spatial frequency
- Attenuate achromatic low spatial frequency





Vertically modulated line flash for 10 ms

- Red-green & Achromatic Low SF: Gaussian window $\sigma = 0.15°$
  - 70% below 1 cpd, 95% below 2 cpd
- Achromatic High SF: 14 cpd square wave, height of 1.2°

Schutz et al, *NN*, *2008*

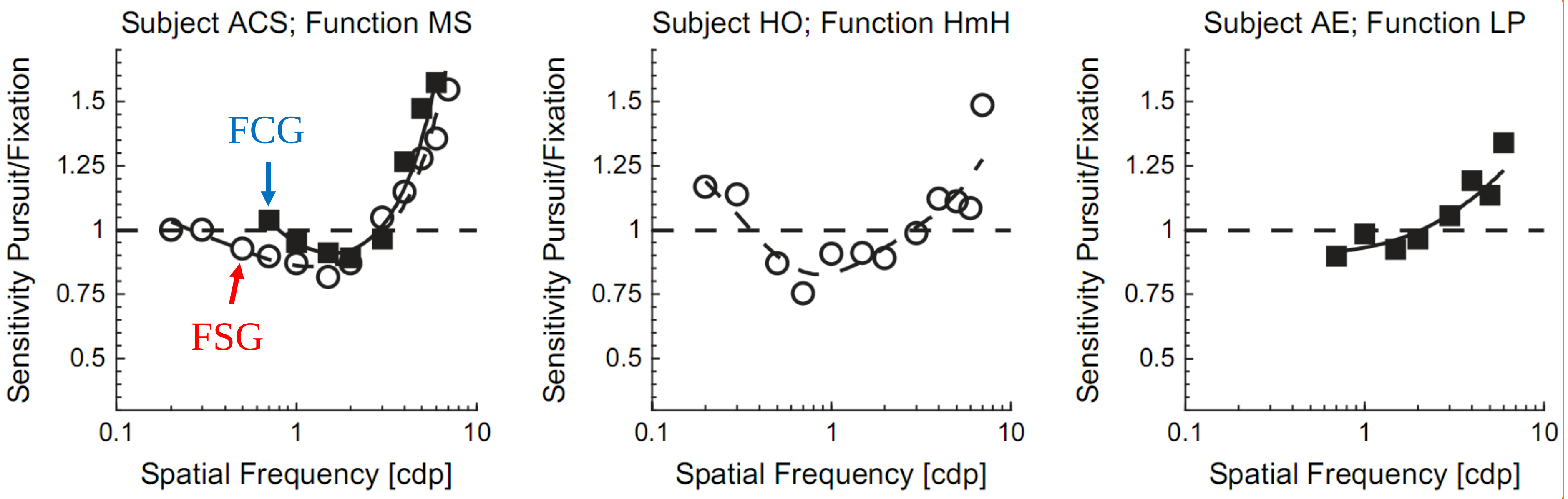
Background: Visual Sensitivity

Non-Retinal Effect

- Enhance color & achromatic high spatial frequency
- Attenuate achromatic low spatial frequency

Foveal gabor detection task:

- Size:
  - FSG: fixed Gaussian window $\sigma = 1°$
  - FCG: fixed number of sine cycles $\sigma = 4/f$
- Orientation:
  - Horizontal
- Flash for 1 frame (10 ms):
  - When eye reached screen center



Schutz et al, *VisRes*, *2009*

Background: Summary & Scientific Questions

Summary

- Smooth pursuit velocity is often slower than that of the target, resulting in catch-up saccades
  - However, there are still retinal motion and saccades even when pursuit is very accurate
- Spatio-temporal sensitivity is modulated/shifted by retinal motion resulted from imperfect pursuit
- Smooth pursuit also has non-retinal effect on visual sensitivity:
  - Enhance for color and achromatic high spatial frequency
  - Attenuate achromatic low spatial frequency

Scientific Questions

- **What are the characteristics of smooth pursuit eye movements?**

  pursuit component + **drift-like component (VS fixation?)**
  (fixation was 0-velocity “smooth pursuit” (Steinman 1990))

- **For perfect pursuit, how does retinal motion (caused by drift-like component) affect visual sensitivity for different spatial frequencies?**
  - The more the retinal motion, the higher sensitivity to low SF and lower sensitivity to high SF (This is opposite to non-retinal effects)

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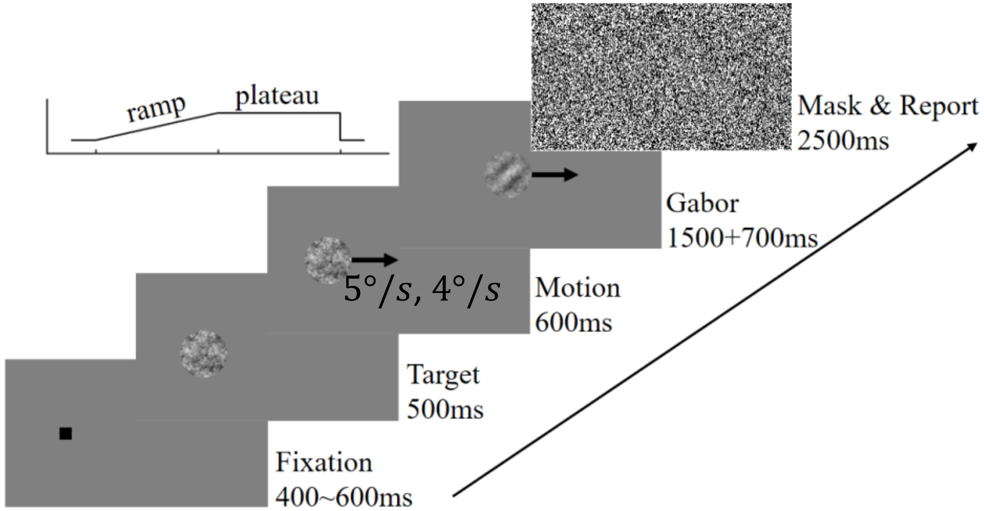
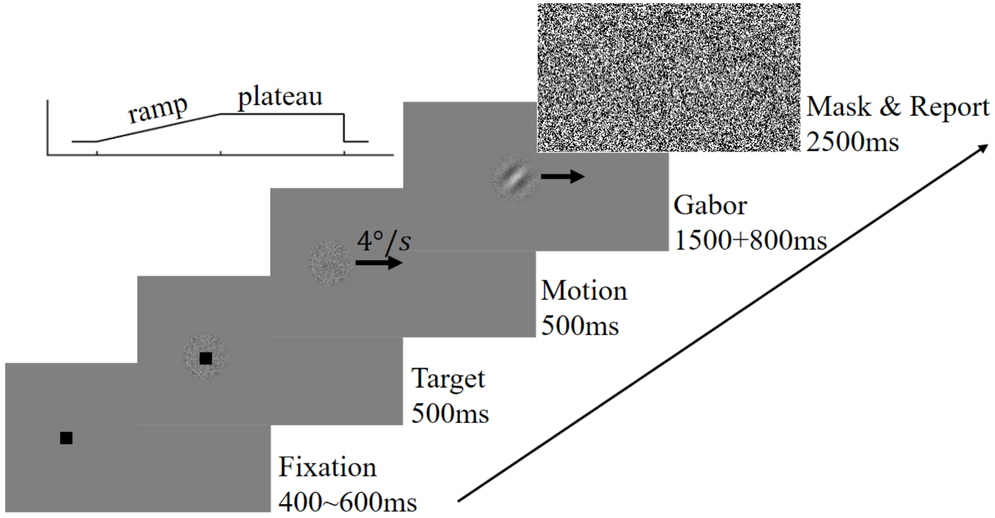
❖ Preliminary Experiments & Data: Paradigms

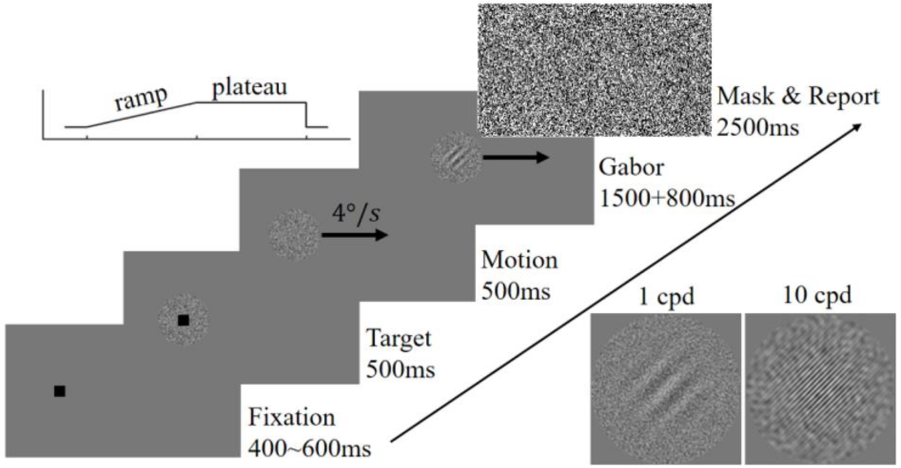
Natural Noise Target



White Noise Target



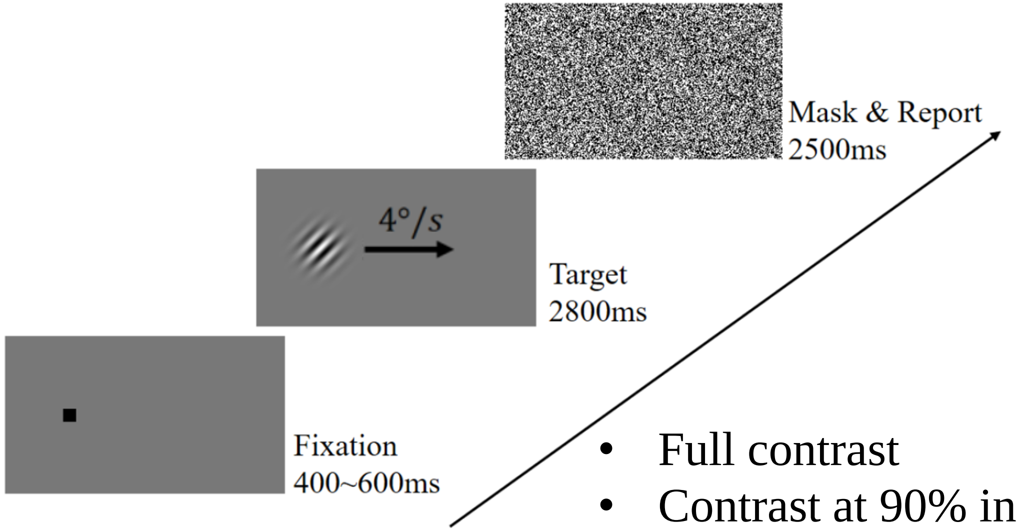
Band Noise Target



$$S_1 = 128c\cos\{2\pi[x\cos(\alpha) - y\sin(\alpha)] + \beta\} \times 0.1 + 128\boxed{N_h \times 0.9} + 128$$

$$S_{10} = 128c\cos\{20\pi[x\cos(\alpha) - y\sin(\alpha)] + \beta\} \times 0.5 + 128\boxed{N_l \times 0.5} + 128$$

No Noise | Full Contrast / Contrast @ 90% Correct Rate



- Full contrast
- Contrast at 90% in pursuit

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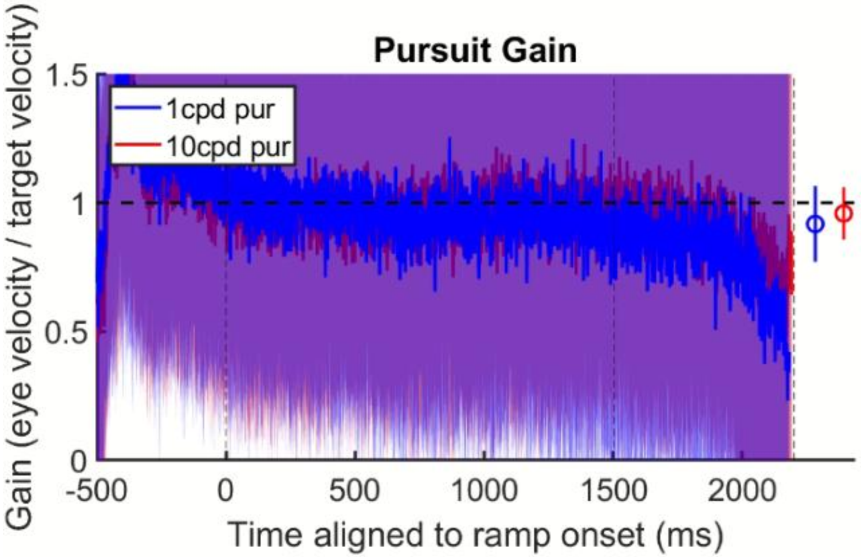
❖ Preliminary Experiments & Data: Pursuit Gain

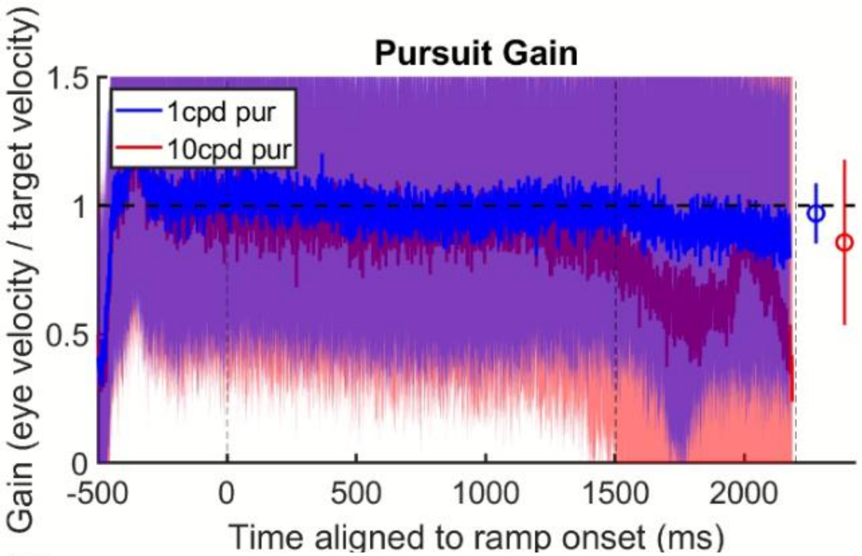
Natural Noise Target

Pursuit gain: A025: $g_1 < g_{10} < 1$; A049: $g_{10} < g_1 < 1$;
A049(4deg): $g_1 \approx g_{10} \approx 1$

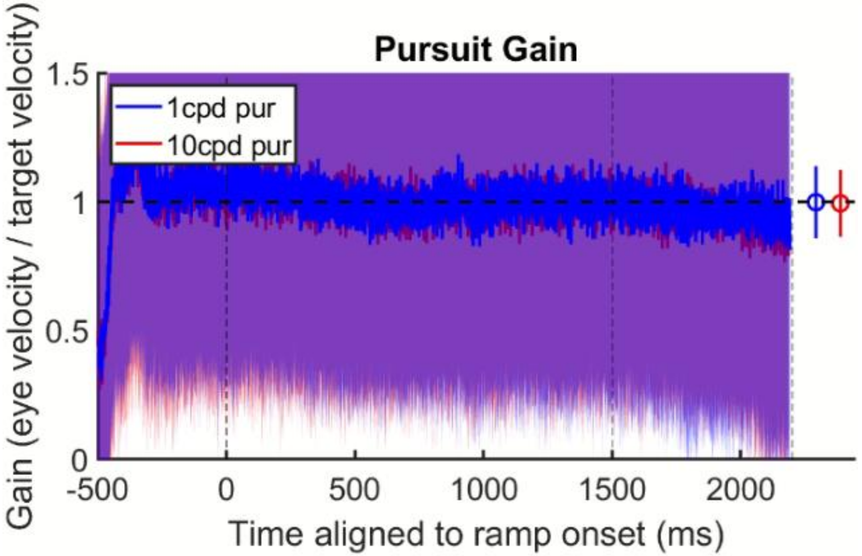
A025, $5°/s$, $g_1 < g_{10}$



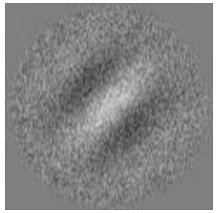
A049, $5°/s$
$g_1 > g_{10}$



A049, $4°/s$



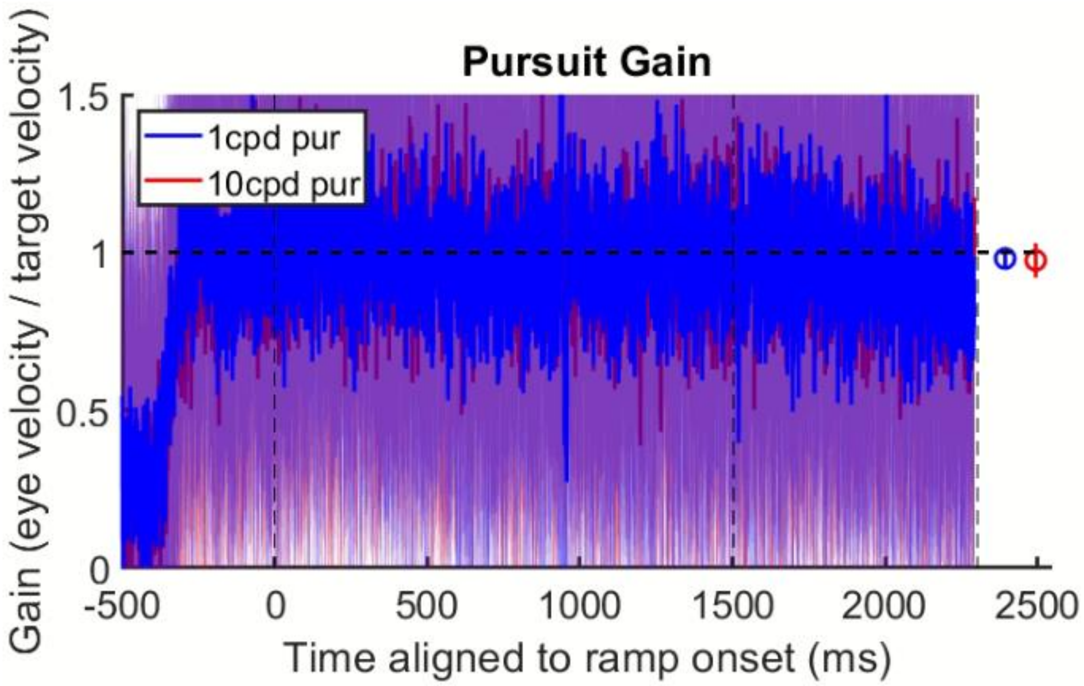
❖ Preliminary Experiments & Data: Pursuit Gain



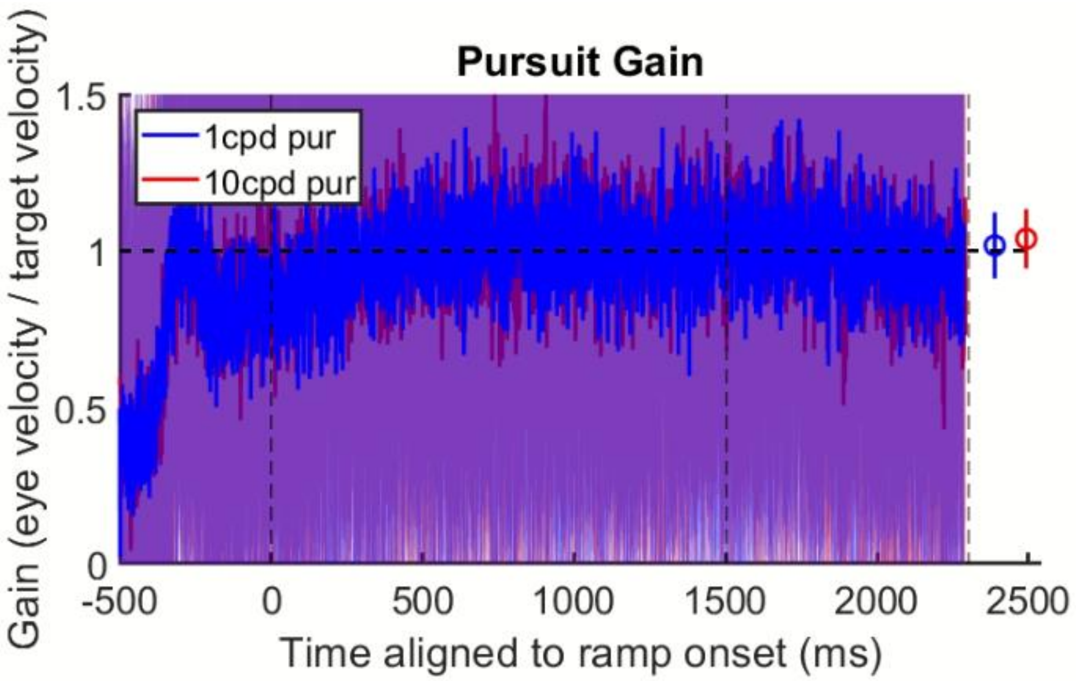
White Noise Target

Pursuit gain: A016: $g_1 \approx g_{10} < 1$; Bin: $g_1 \approx g_{10} > 1$

A016



Bin



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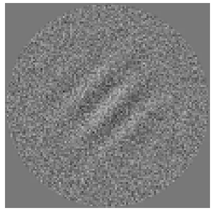
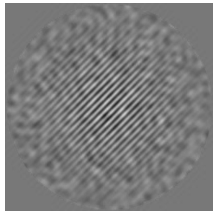
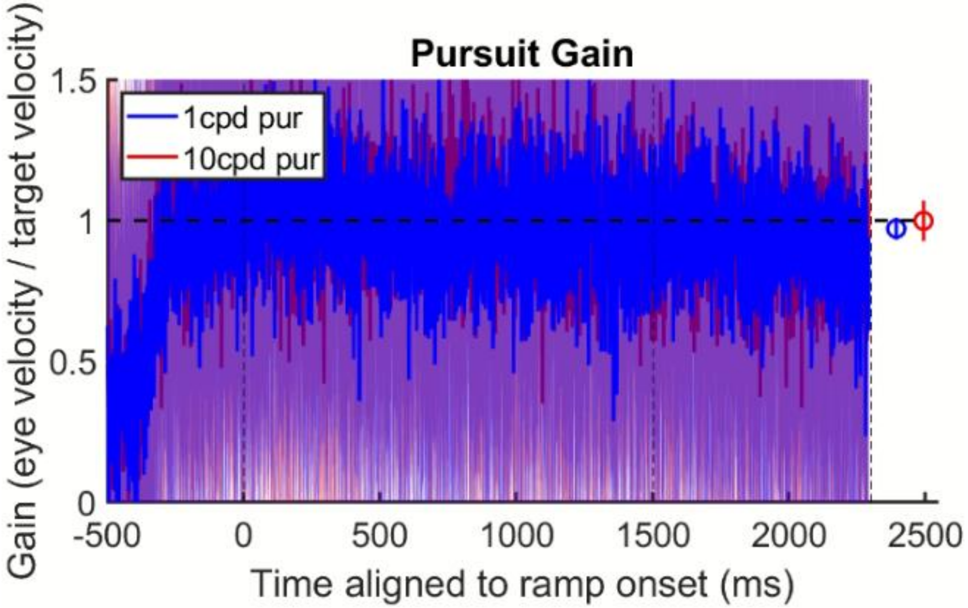




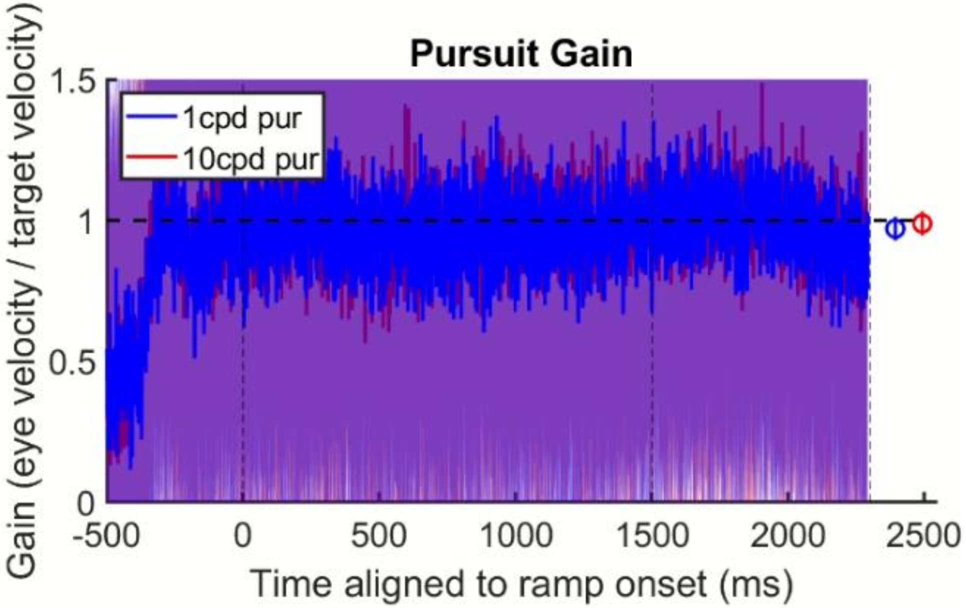
Band Noise Target

Pursuit gain: A016: $g_1 < g_{10} \approx 1$; Bin: $g_1 < g_{10} < 1$

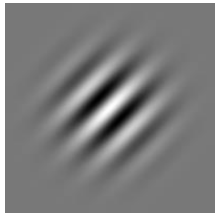
A016



Bin



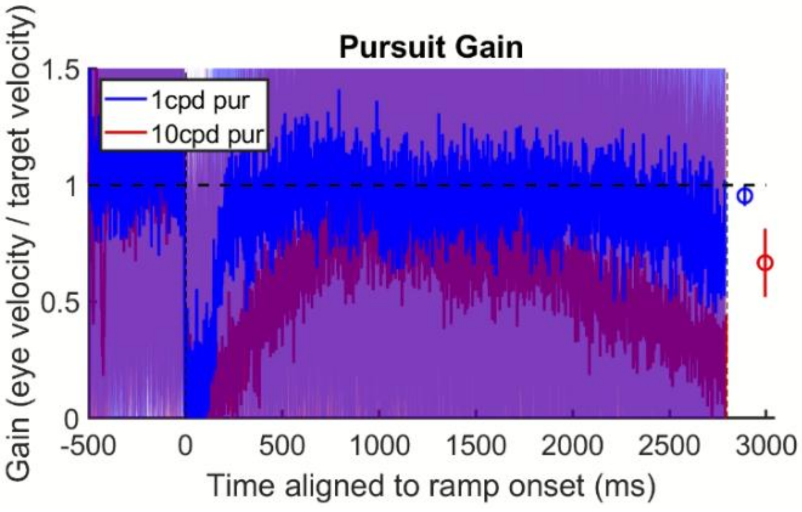
❖ Preliminary Experiments & Data: Pursuit Gain



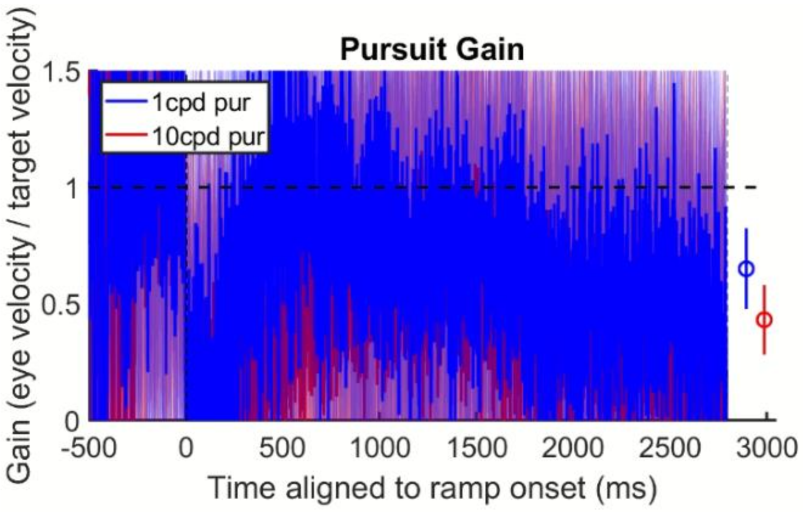
No Noise | Full Contrast

Pursuit gain: $g_{10} < g_1 < 1$

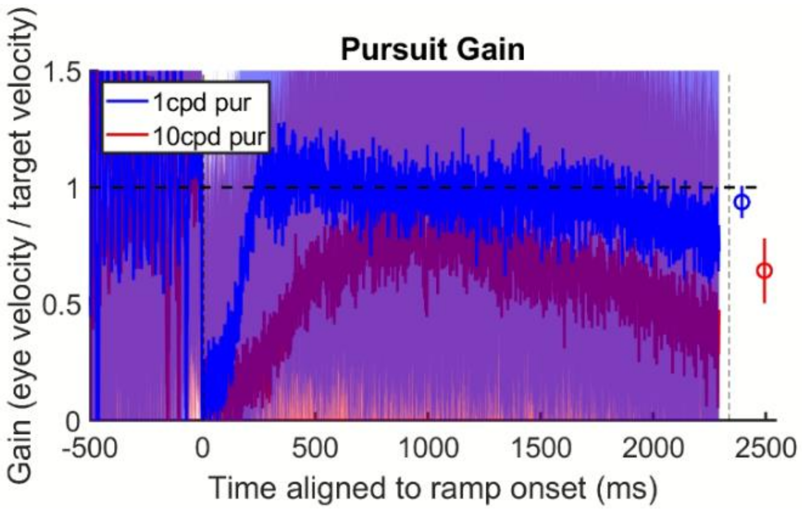
A016



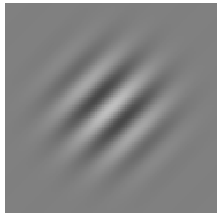
A027



A056



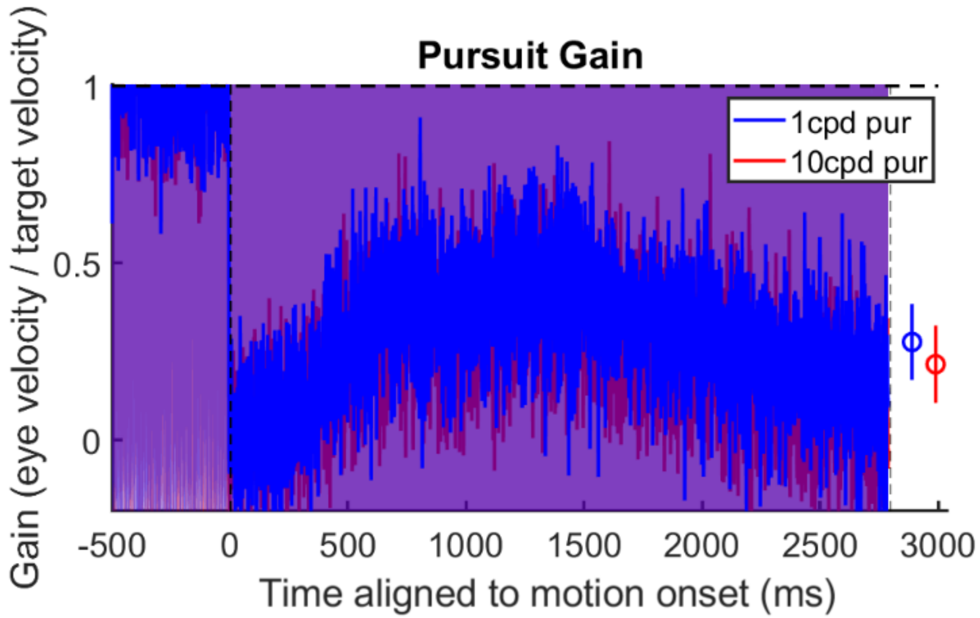
❖ Preliminary Experiments & Data: Pursuit Gain



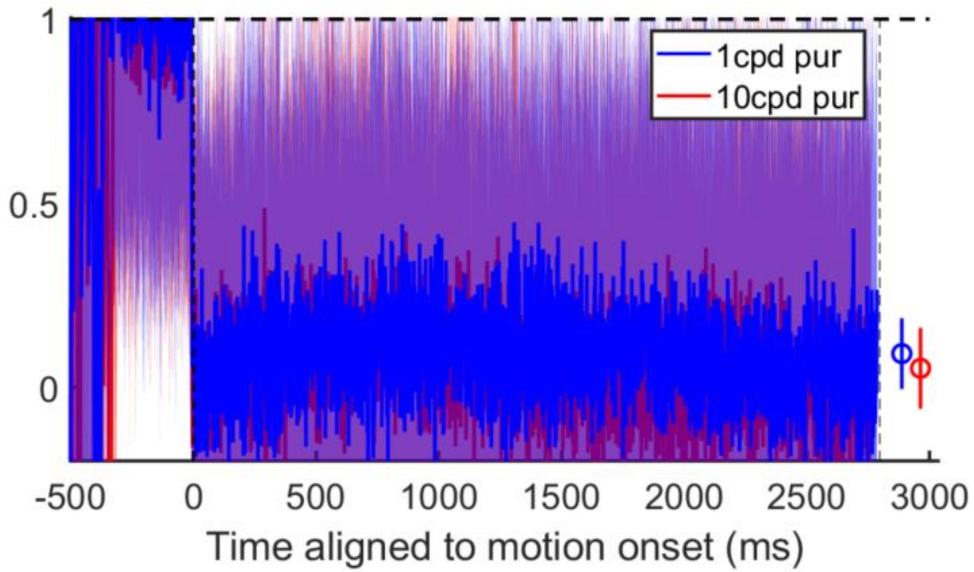
No Noise | Contrast 90%

Pursuit gain: $g_{10} < g_{11} \ll 1$

Bin



A081



❖ Preliminary Experiments & Data: Pursuit Gain

Interim Summary

- When there is a high-contrast noise patch, the pursuit gain was very close to 1;
  Although still significantly smaller than 1 for most conditions

- Pursuit gain is substantially below 1 when there is no high-contrast noise patch.

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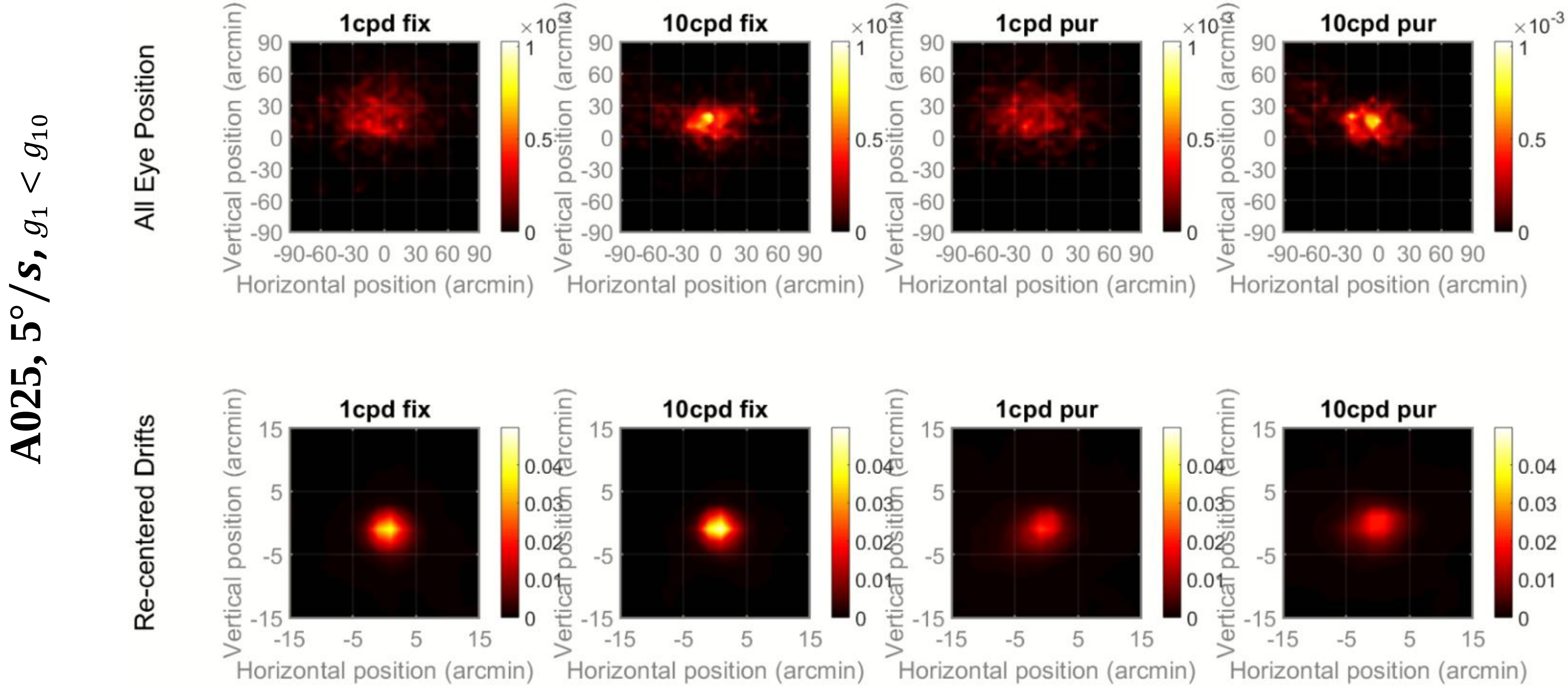
❖ Preliminary Experiments & Data: Drifts

Natural Noise Target

Eye Position Distribution (**Relative**): Natural Noise Target

- Diffused to left ($g_1 < g_{10} < 1$)



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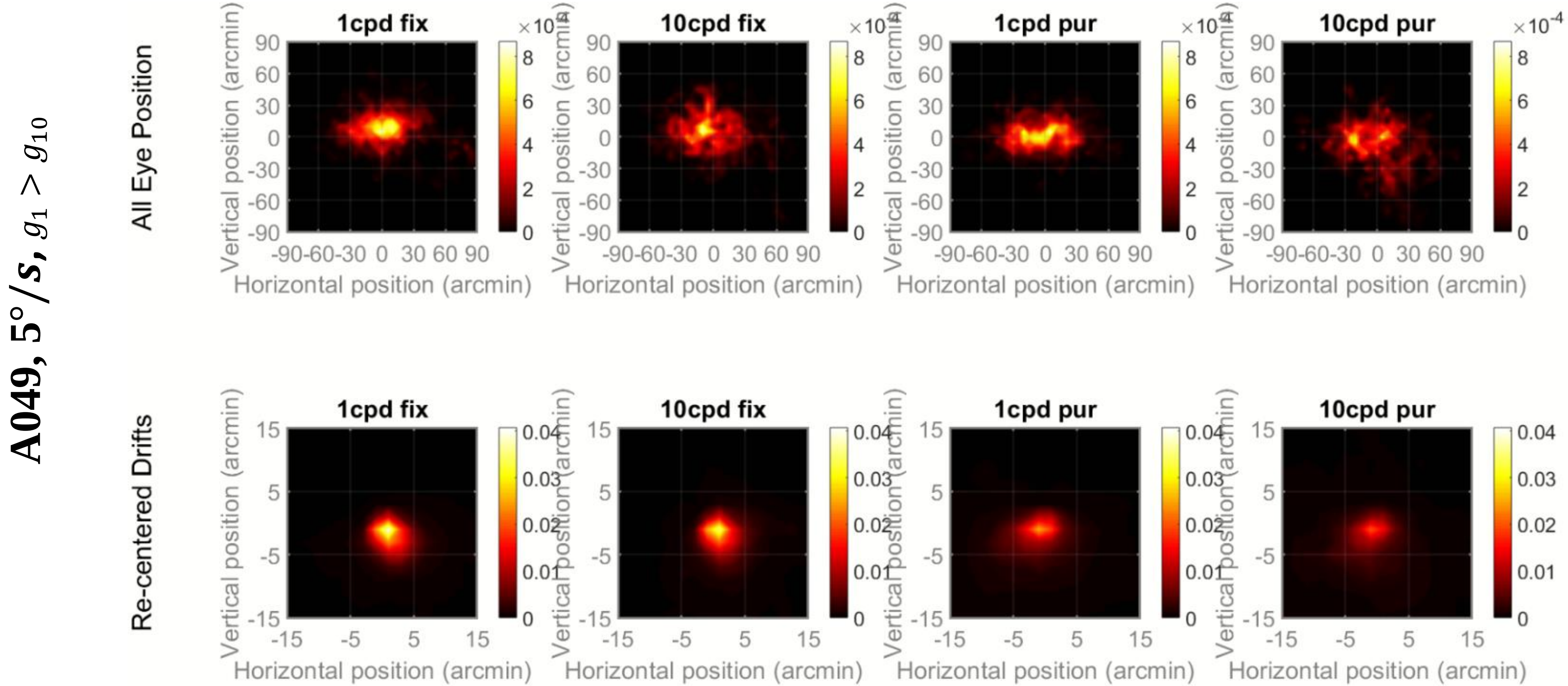
Eye Position Distribution (**Relative**): Natural Noise Target

➢ Diffused to left ($g_{10} < g_1 < 1$)



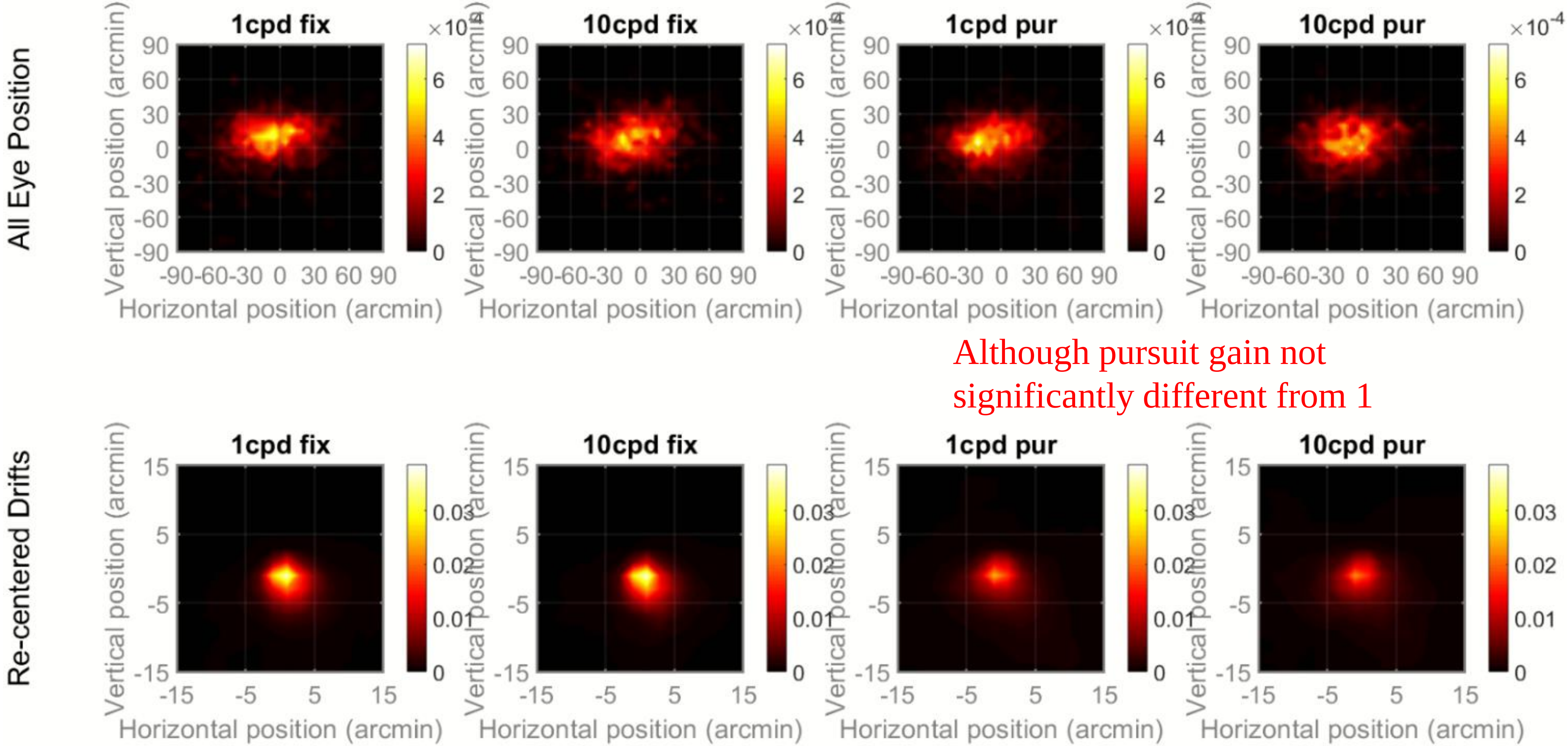
❖ Preliminary Experiments & Data: Drifts

Natural Noise Target

Eye Position Distribution (**Relative**): Natural Noise Target

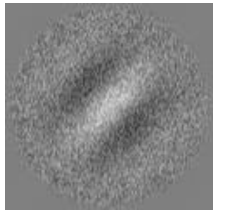
- ➢ Diffused to left

A049, 4°/s



Although pursuit gain not significantly different from 1

❖ Preliminary Experiments & Data: Drifts

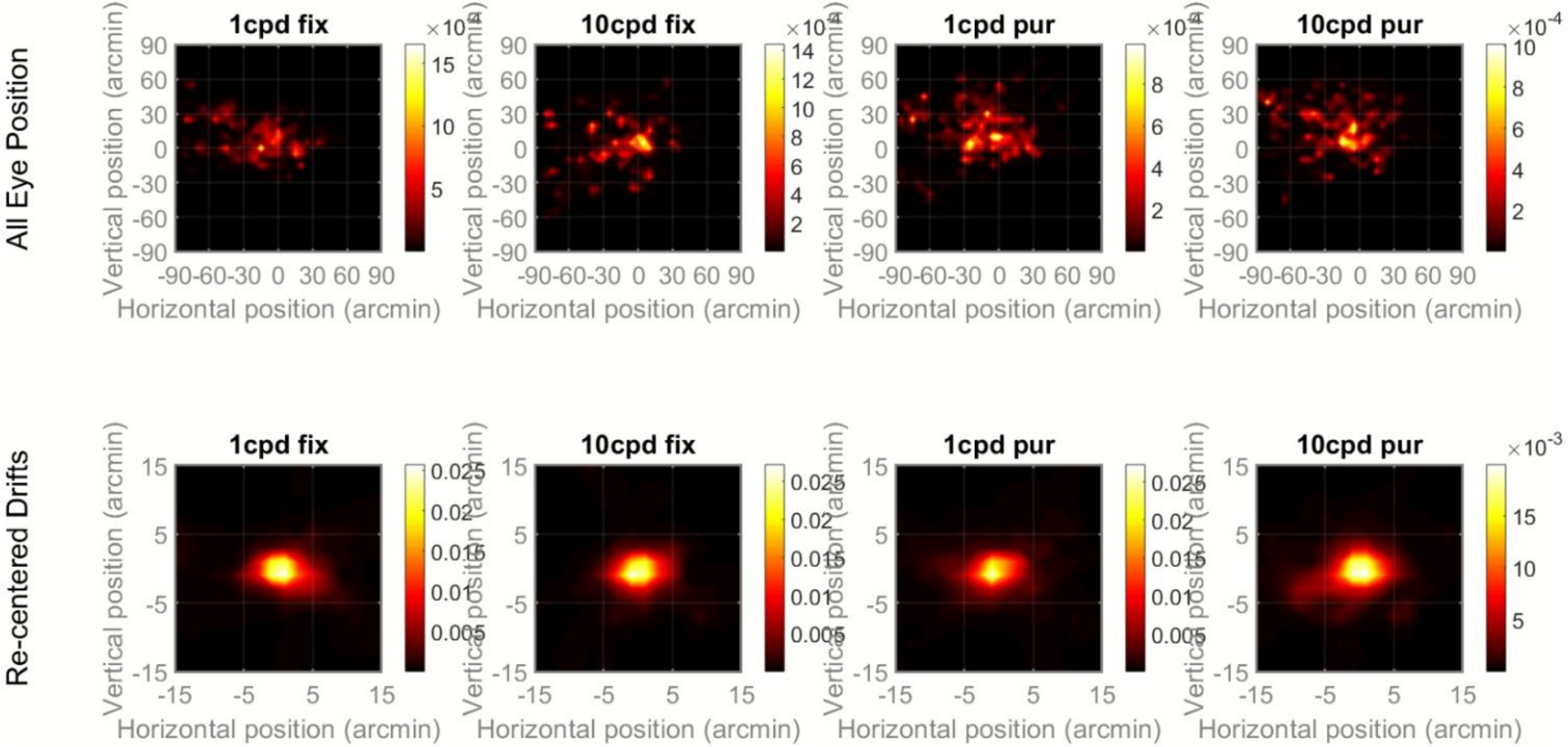


White Noise Target

Eye Position Distribution (**Relative**): White Noise Target

➢ Diffused to left ($g_1 \approx g_{10} < 1$)

A016



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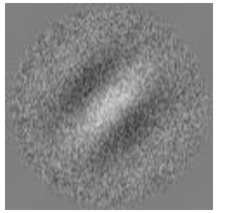
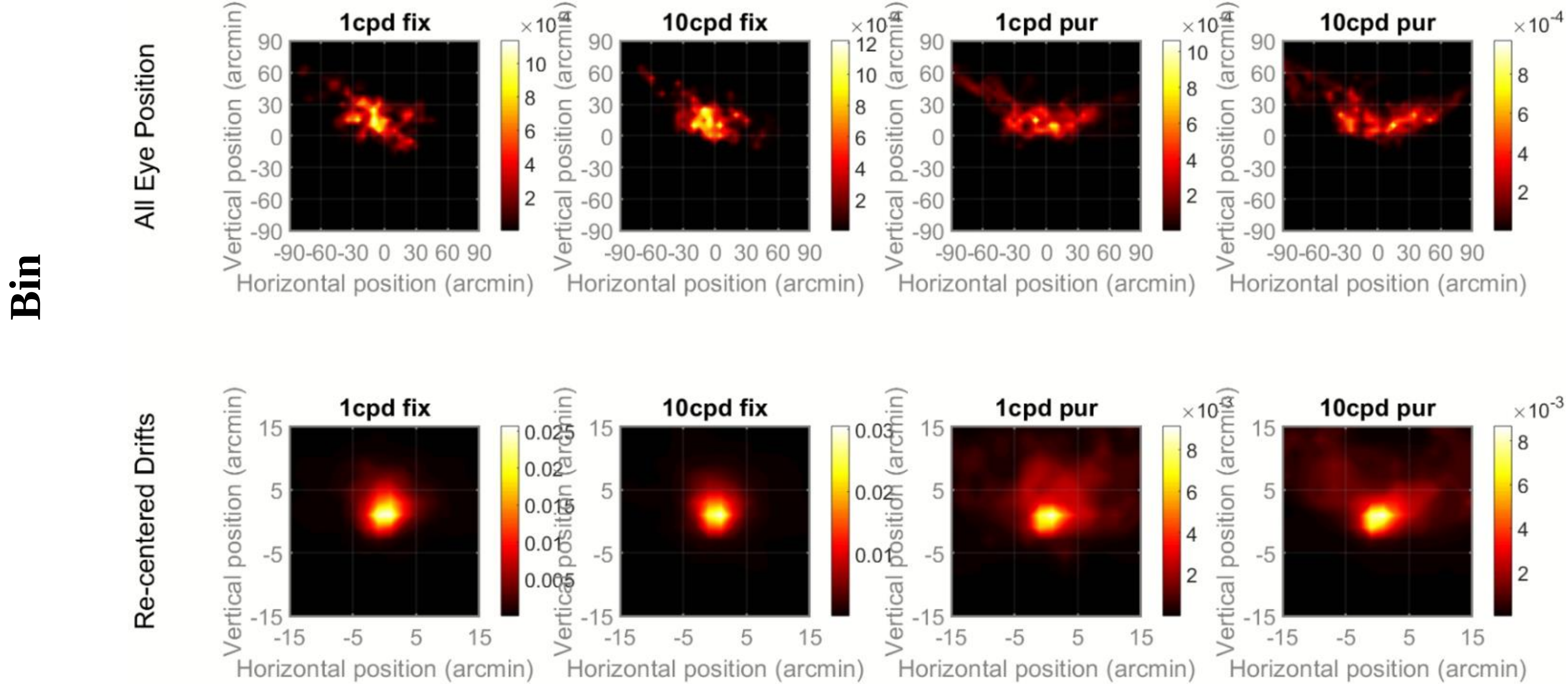


White Noise Target

Eye Position Distribution (**Relative**): White Noise Target

➢ Diffused to both left and right ($g_1 \approx g_{10} > 1$)



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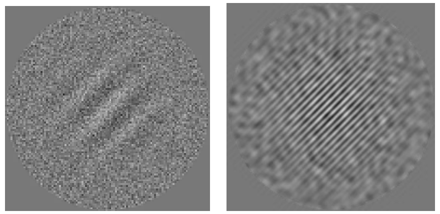
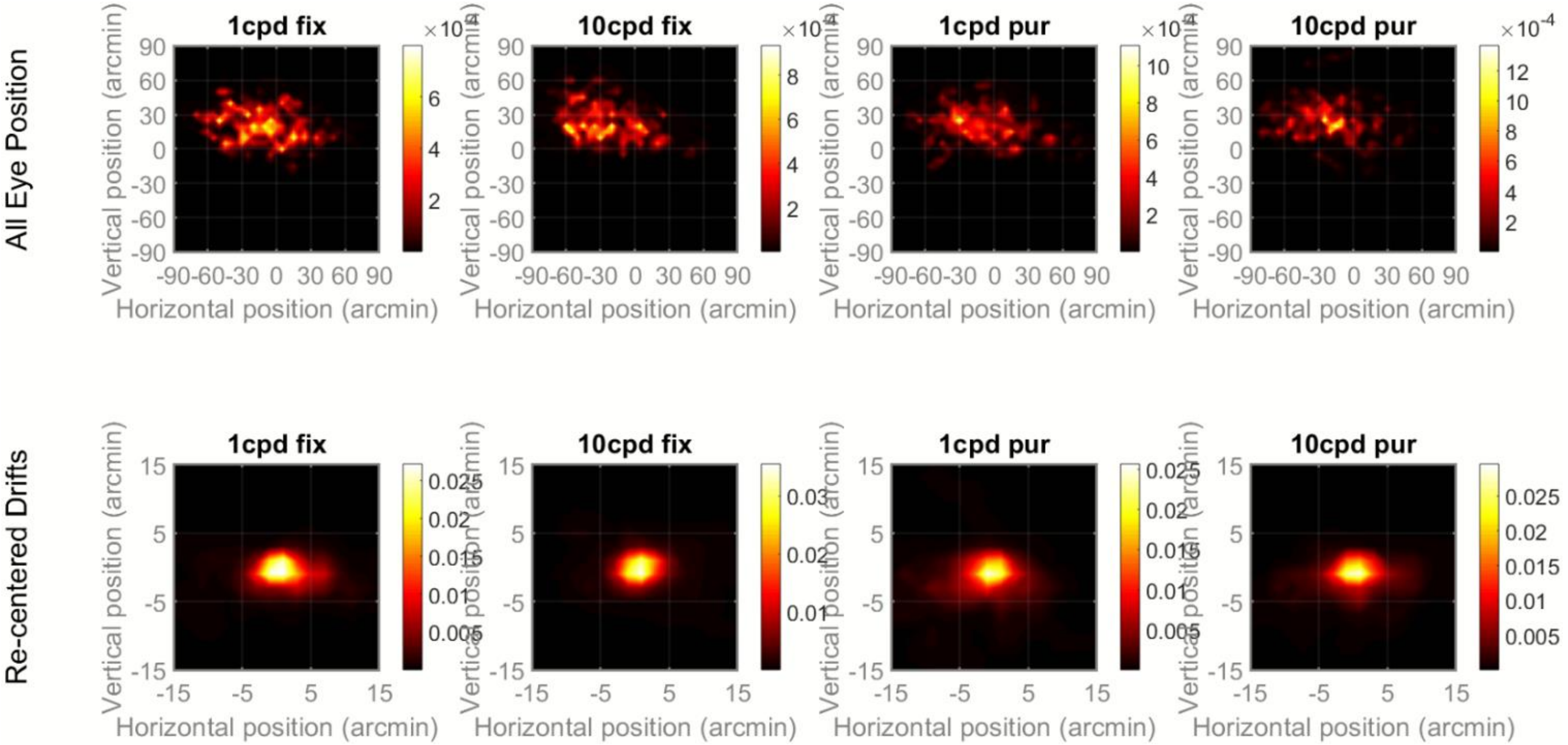


Band Noise Target

Eye Position Distribution (**Relative**): Band Noise Target

➢ Diffused to left ($g_1 < g_{10} \approx 1$)

A016



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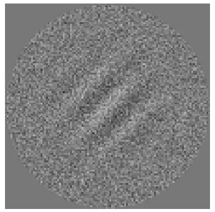
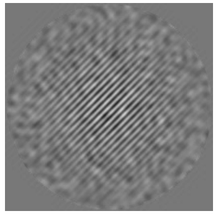
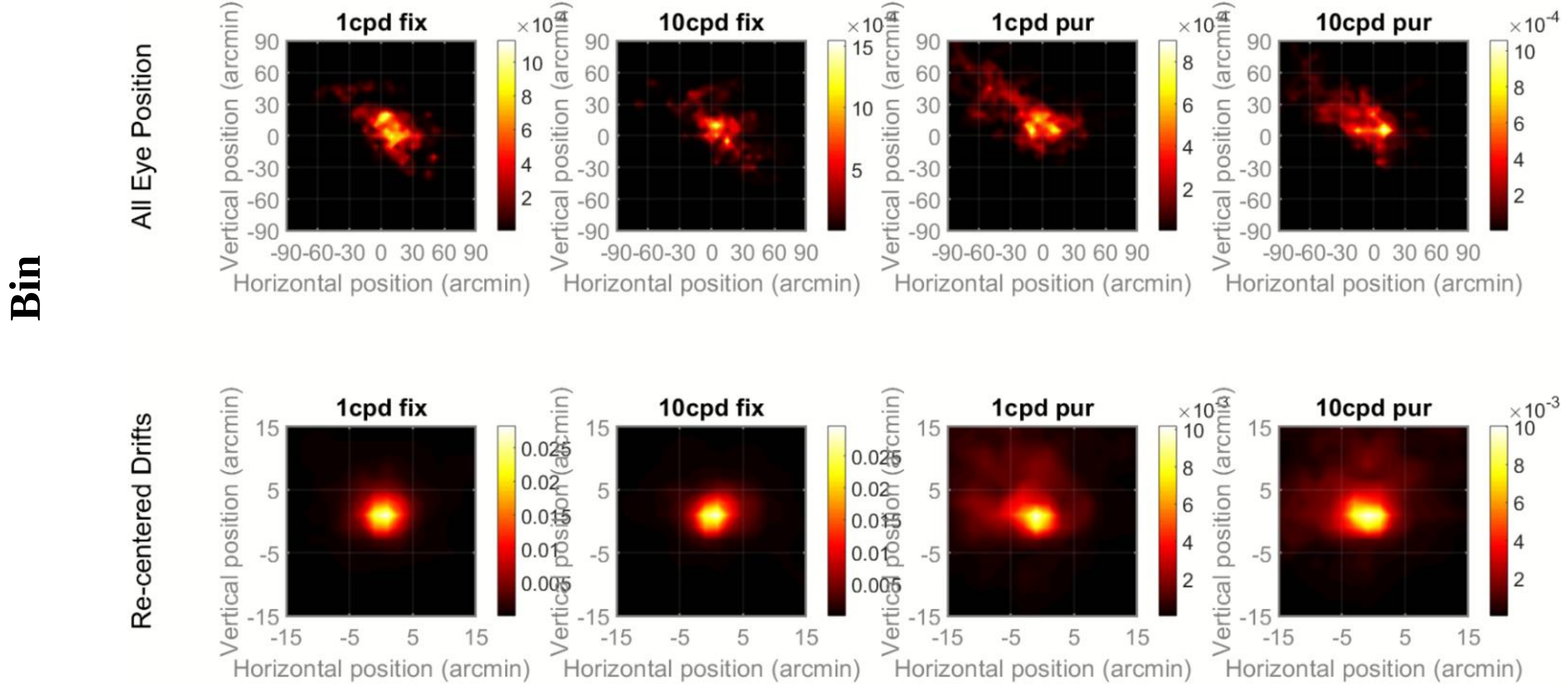




Band Noise Target

Eye Position Distribution (**Relative**): Band Noise Target

- Diffused to left ($g_1 < g_{10} < 1$)



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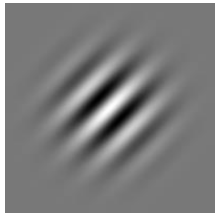
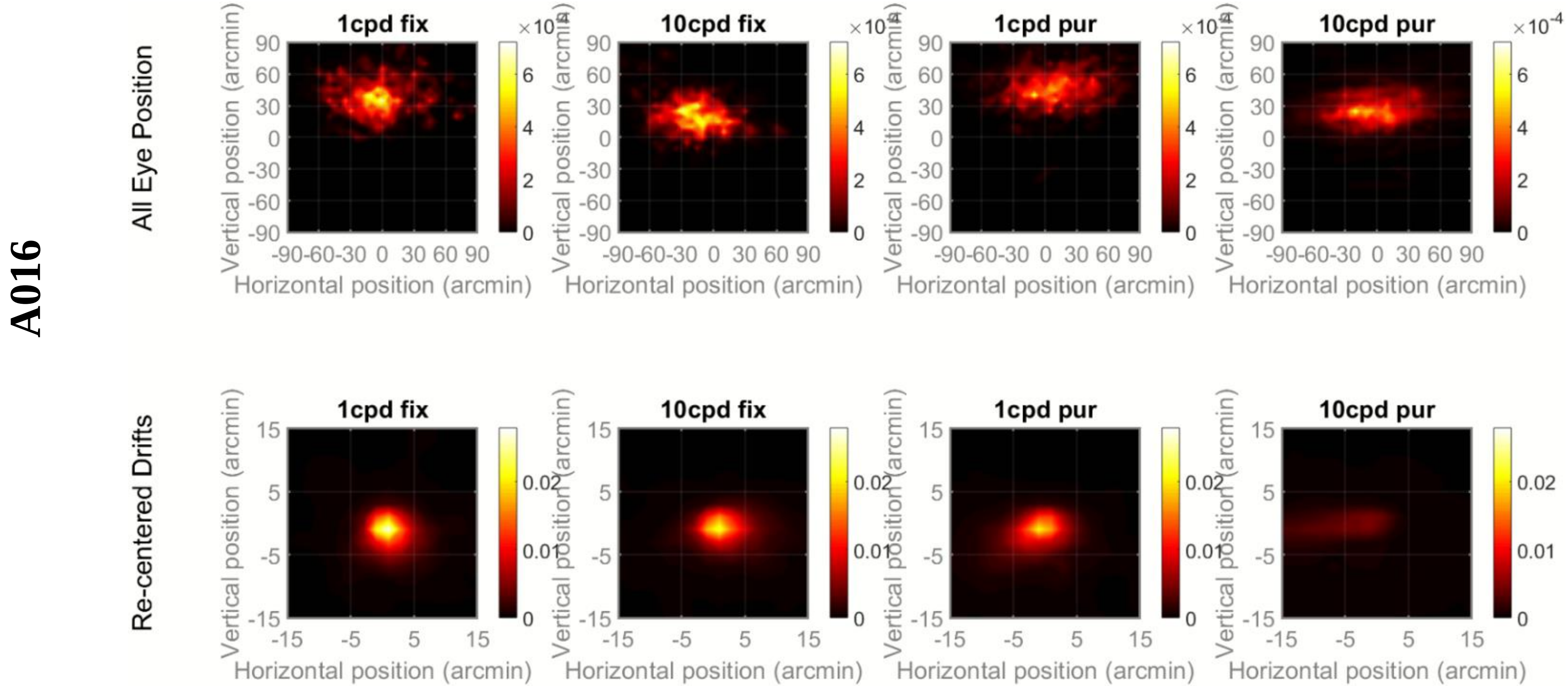


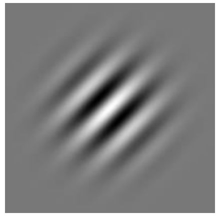
No Noise | Full Contrast

Eye Position Distribution (**Relative**): No Noise | Full Contrast

➢ Diffused to left ($g_{10} < g_1 < 1$)



❖ Preliminary Experiments & Data: Drifts

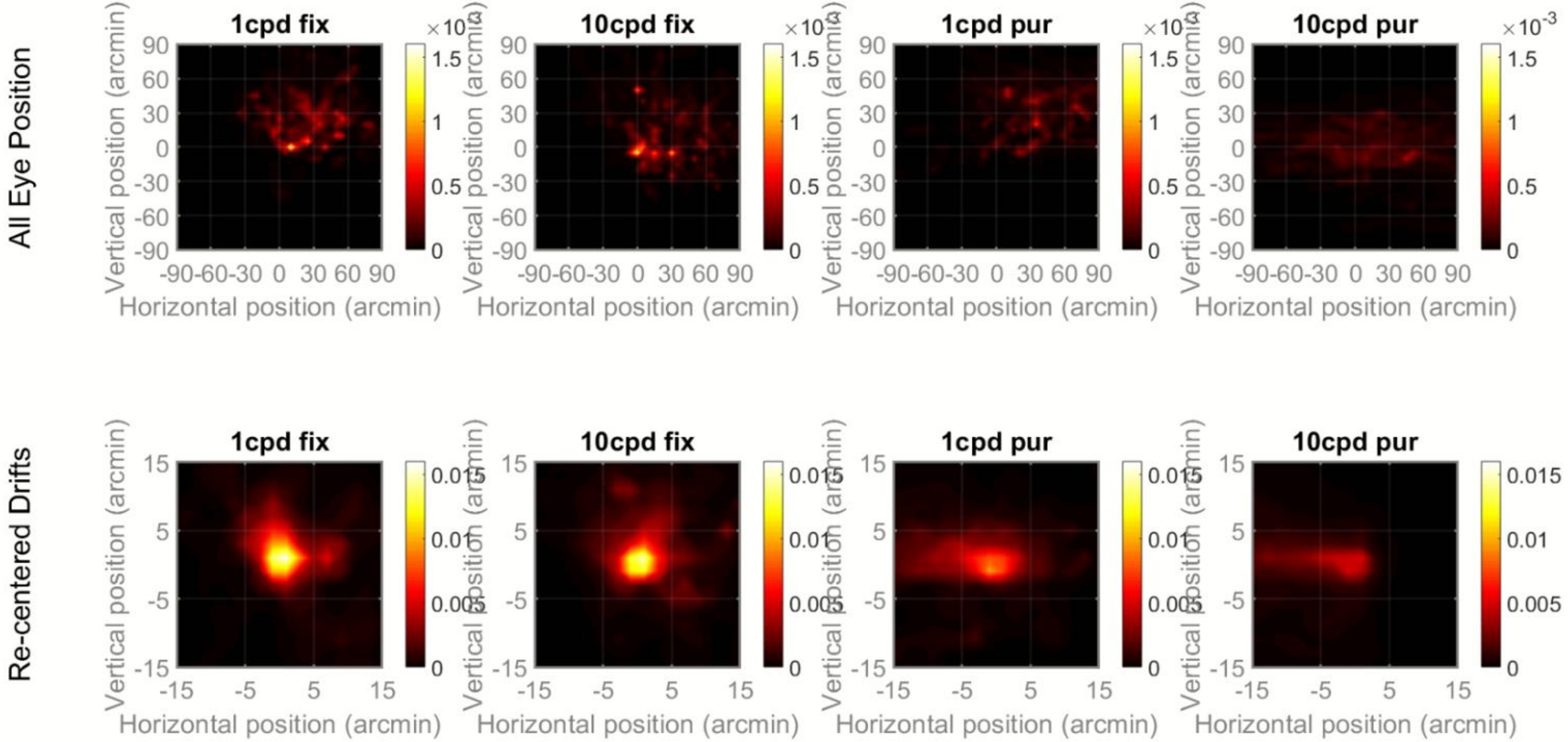


No Noise | Full Contrast

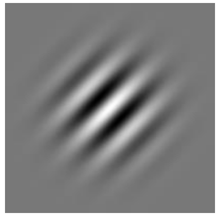
Eye Position Distribution (**Relative**): No Noise | Full Contrast

- Diffused to left ($g_{10} < g_1 < 1$)

A027



❖ Preliminary Experiments & Data: Drifts

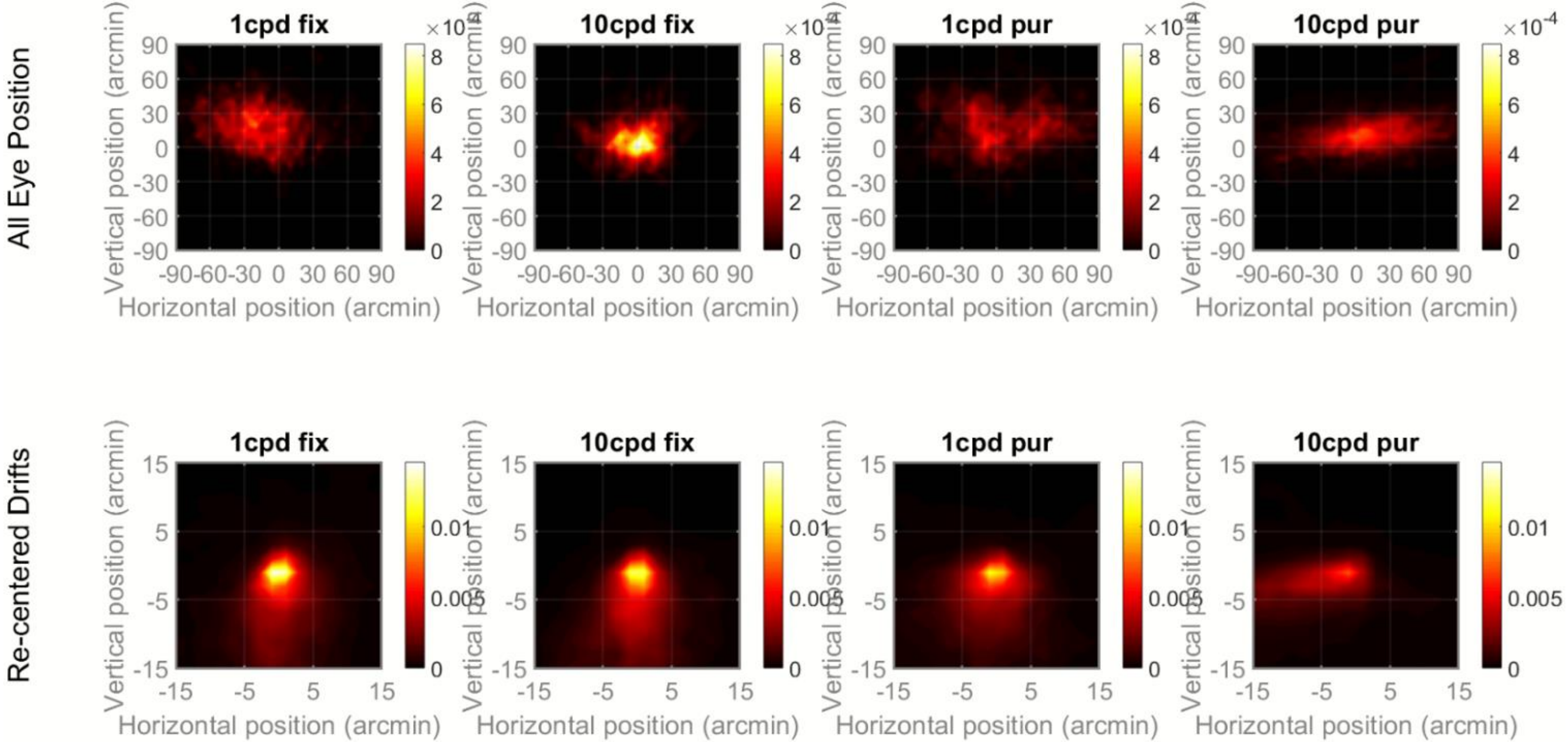


No Noise | Full Contrast

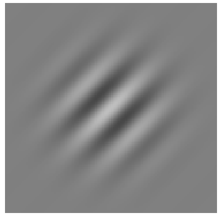
Eye Position Distribution (**Relative**): No Noise | Full Contrast

➢ Diffused to left ($g_{10} < g_1 < 1$)

A056



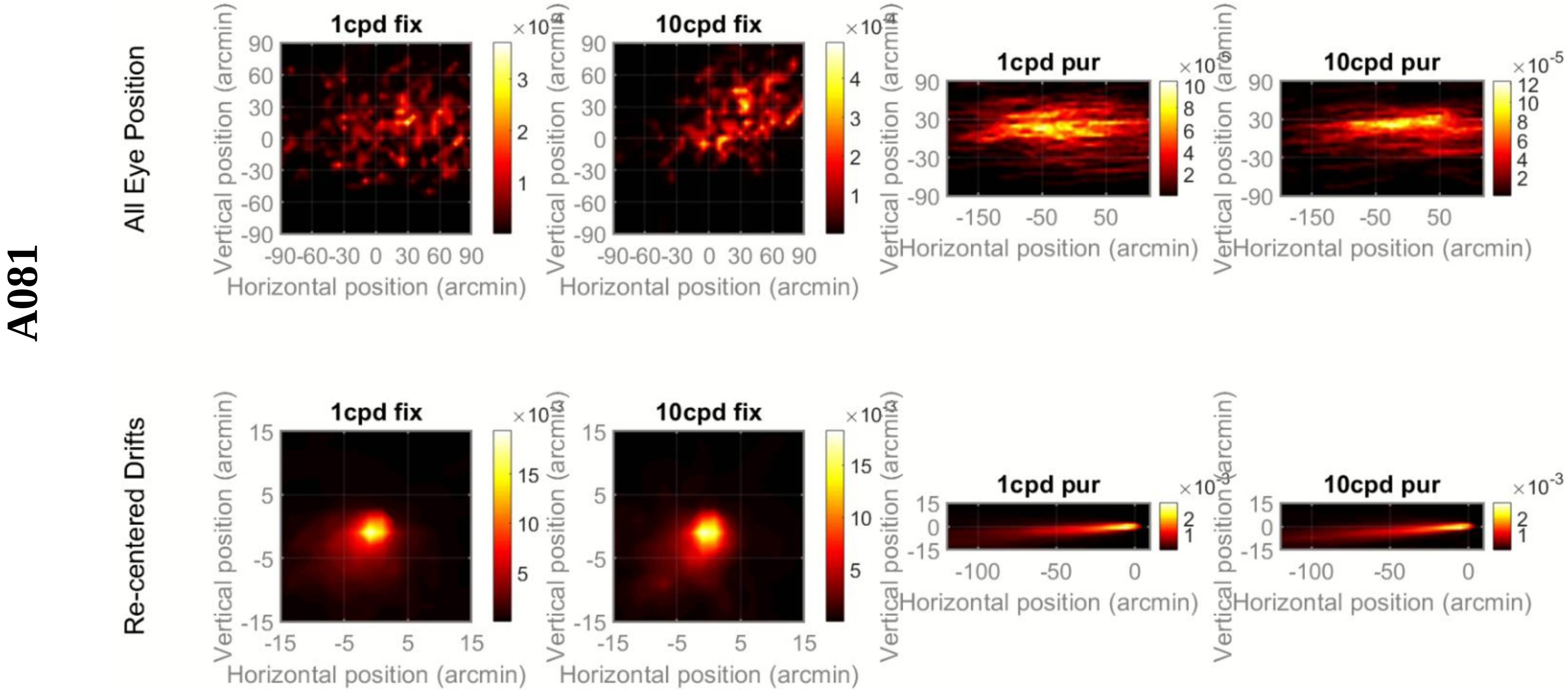
❖ Preliminary Experiments & Data: Drifts



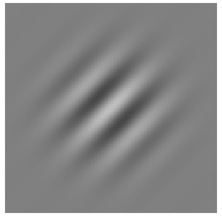
No Noise | Contrast 90%

Eye Position Distribution (**Relative**): No Noise | Contrast at 90%

➢ Diffused to left ($g_{10} < g_1 \ll 1$)



❖ Preliminary Experiments & Data: Drifts

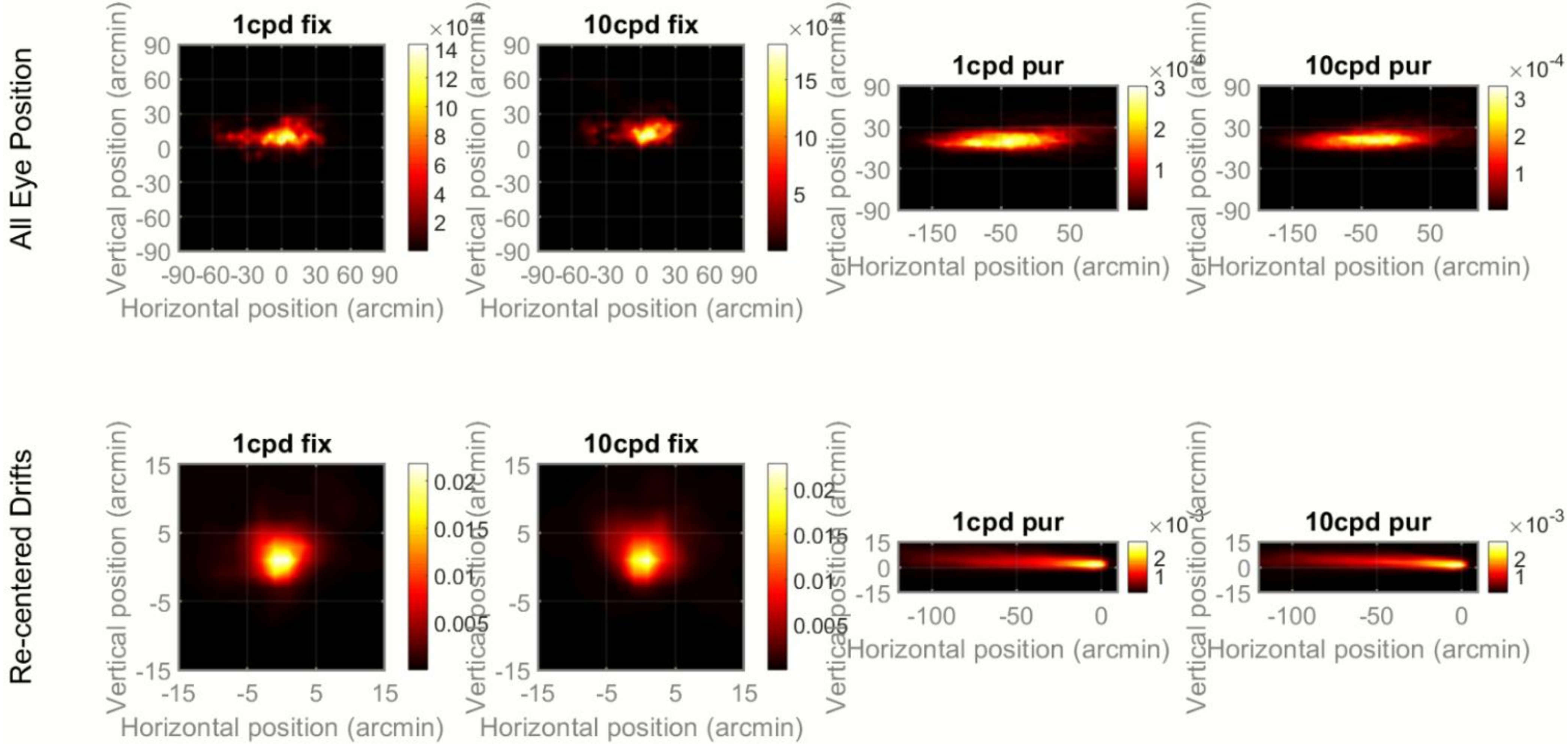


No Noise | Contrast 90%

Eye Position Distribution (**Relative**): No Noise | Contrast at 90%

➢ Diffused to left ($g_{10} < g_1 \ll 1$)

Bin



❖ Preliminary Experiments & Data: Eye Pos Dist

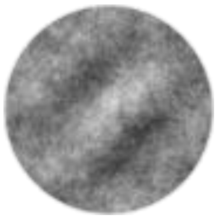
Interim Summary

- Eye position (relative to target) distribution diffused to the left in pursuit trials

OUTLINE

- Background
  - Eye Movement Patterns During Smooth Pursuit
  - Visual Sensitivity during Smooth Pursuit
    - Retinal Effect
    - Non-retinal Effect
  - Summary & Scientific Questions
- **Preliminary Experiments & Data**
  - **Characterize Pursuit EMs:** pursuit gain, pos dist, **vel dist**
  - Factor Analysis
- Brain Storming

❖ Preliminary Experiments & Data: Drifts

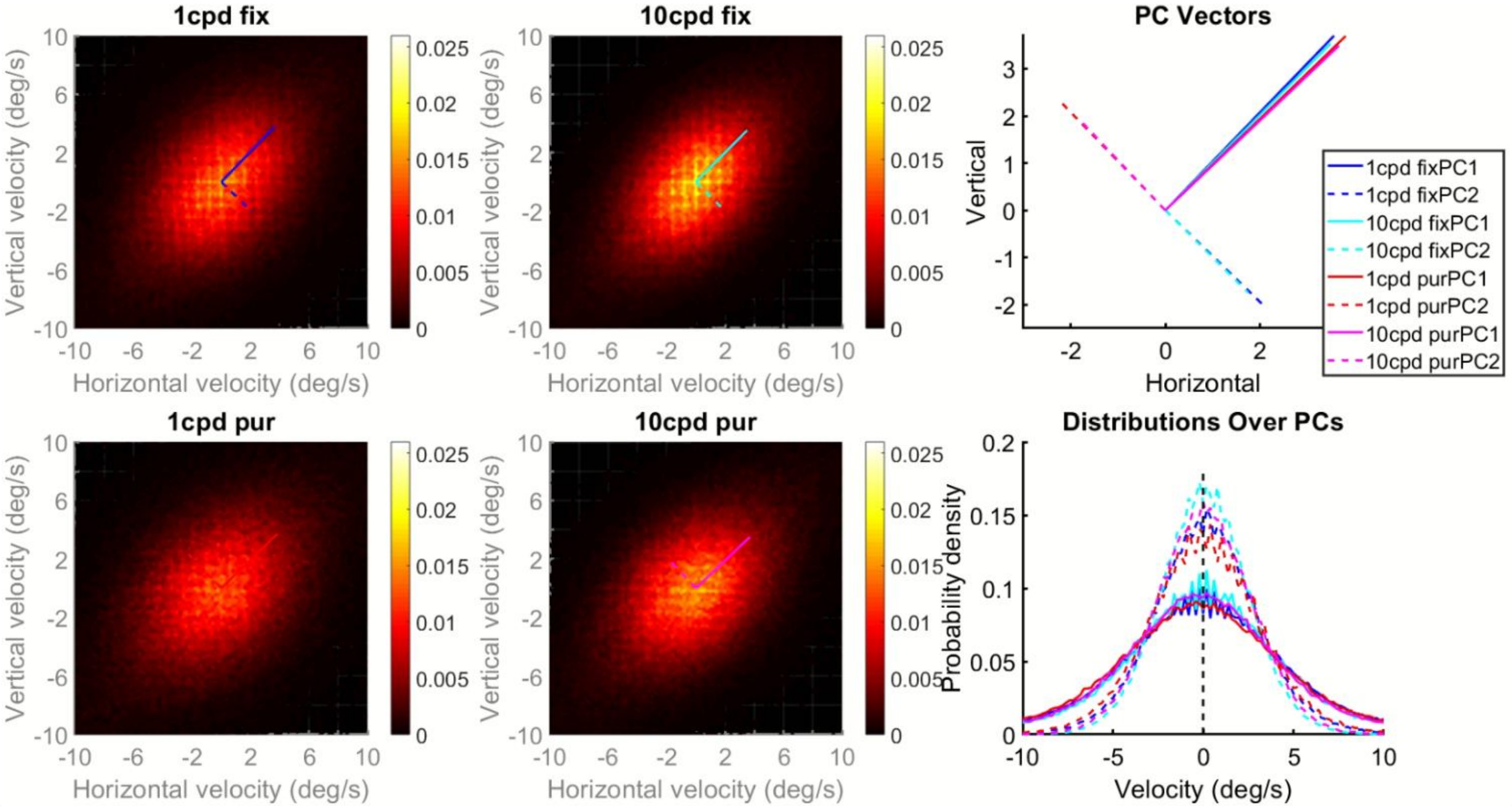


Natural Noise Target

Drift Velocity Distribution (**Relative**): Natural Noise Target

➢ Wider in pursuit trials ($g_1 < g_{10} < 1$)

A025, 5°/s, $g_1 < g_{10}$



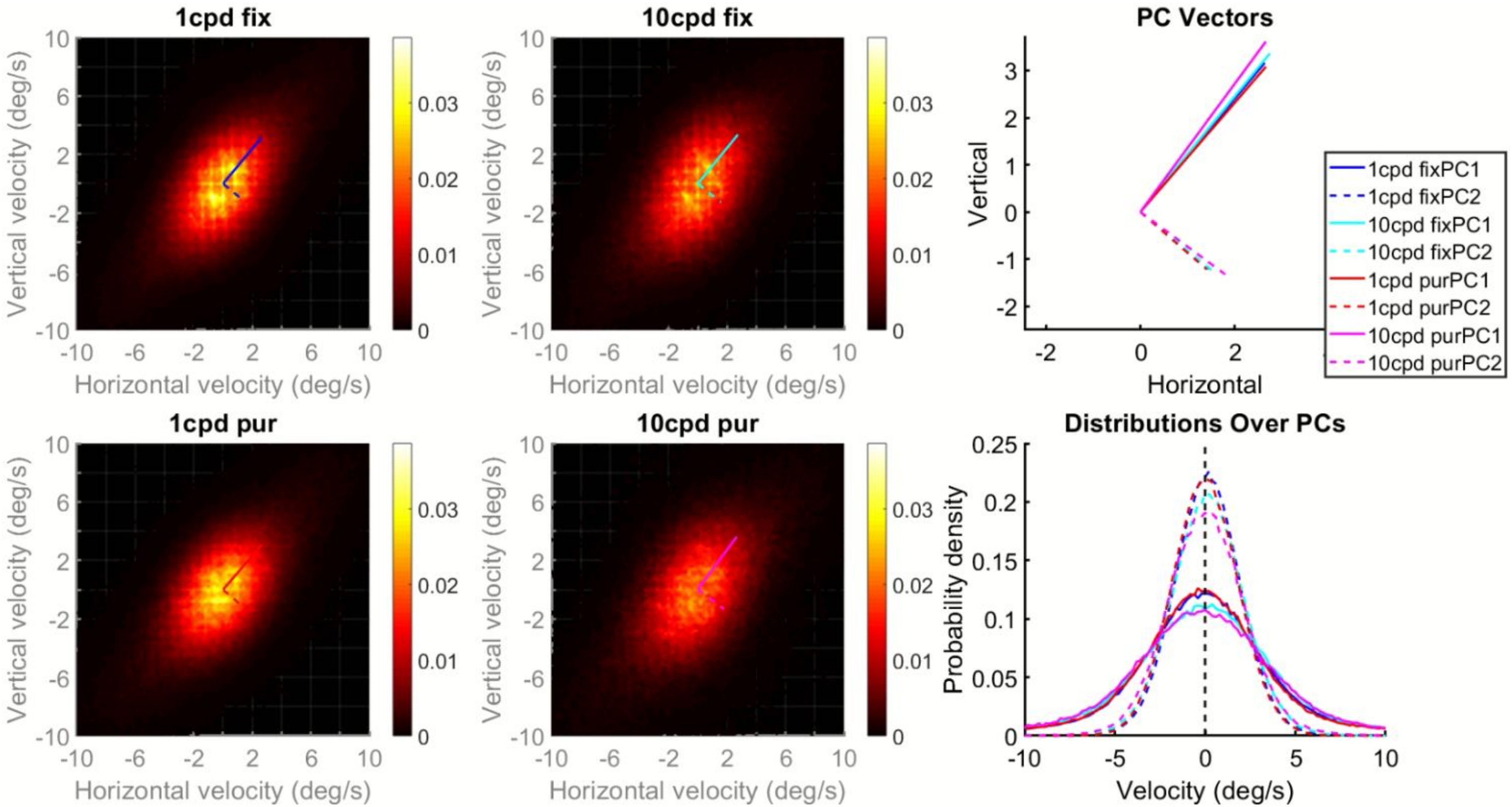
❖ Preliminary Experiments & Data: Drifts

Natural Noise Target

Drift Velocity Distribution (**Relative**): Natural Noise Target

➢ Wider in pursuit trials ($g_{10} < g_1 < 1$)

A049, 5°/s, $g_1 > g_{10}$



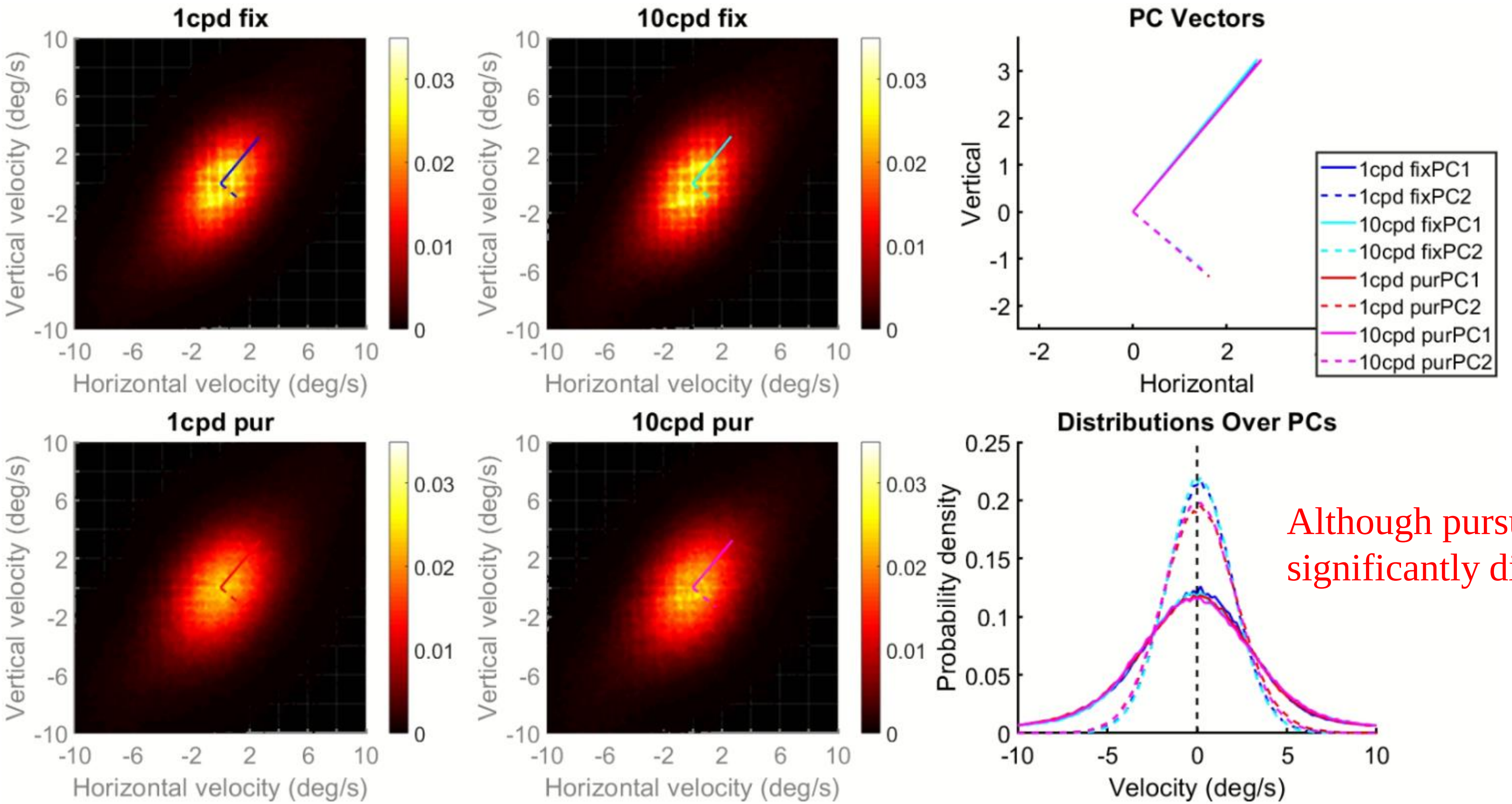
❖ Preliminary Experiments & Data: Drifts

Natural Noise Target

Drift Velocity Distribution (**Relative**): Natural Noise Target

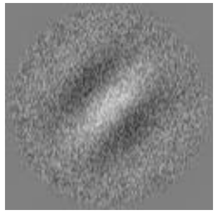
- ➢ Wider in pursuit trials

A049, 4°/s



Although pursuit gain not significantly different from 1

❖ Preliminary Experiments & Data: Drifts

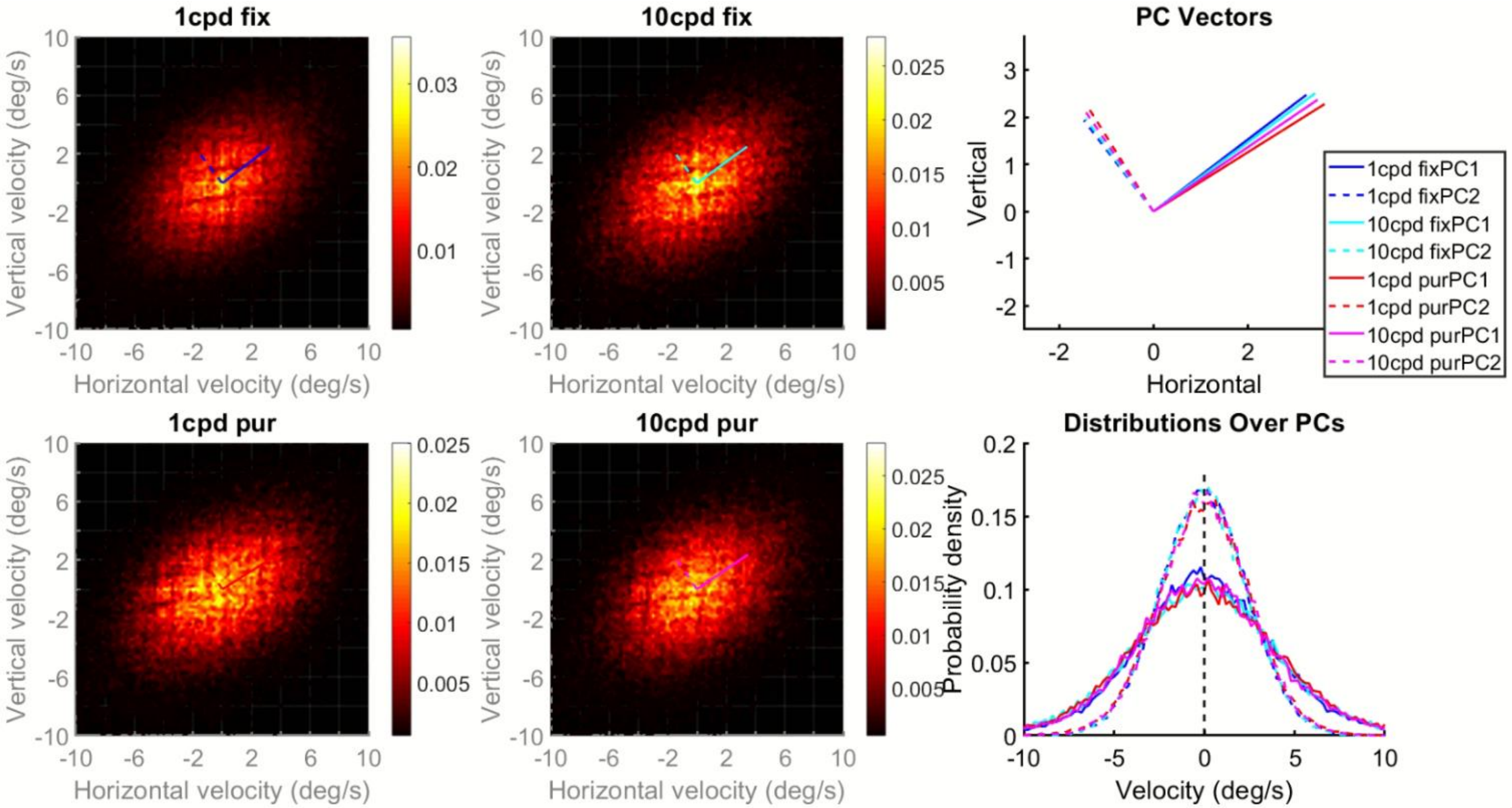


White Noise Target

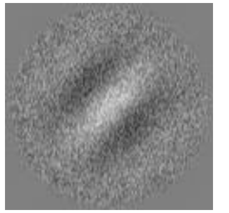
Drift Velocity Distribution (**Relative**): White Noise Target

➢ Wider in pursuit trials ($g_1 \approx g_{10} < 1$)

A016



❖ Preliminary Experiments & Data: Drifts

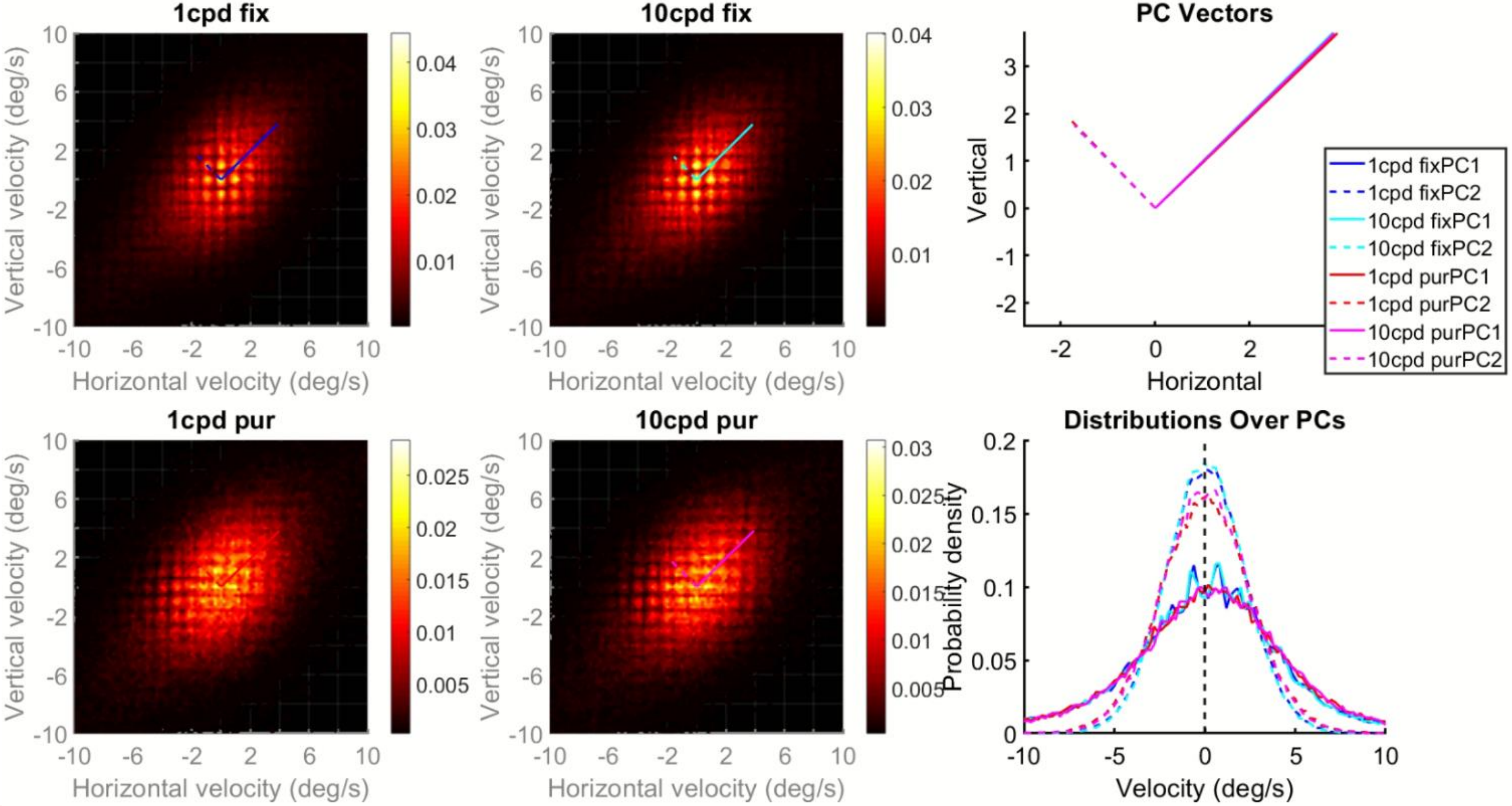


White Noise Target

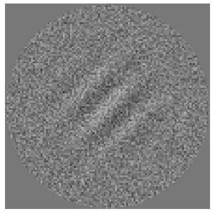
Drift Velocity Distribution (**Relative**): White Noise Target

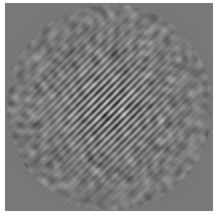
➢ Wider in pursuit trials $(g_1 \approx g_{10} > 1)$

Bin



❖ Preliminary Experiments & Data: Drifts



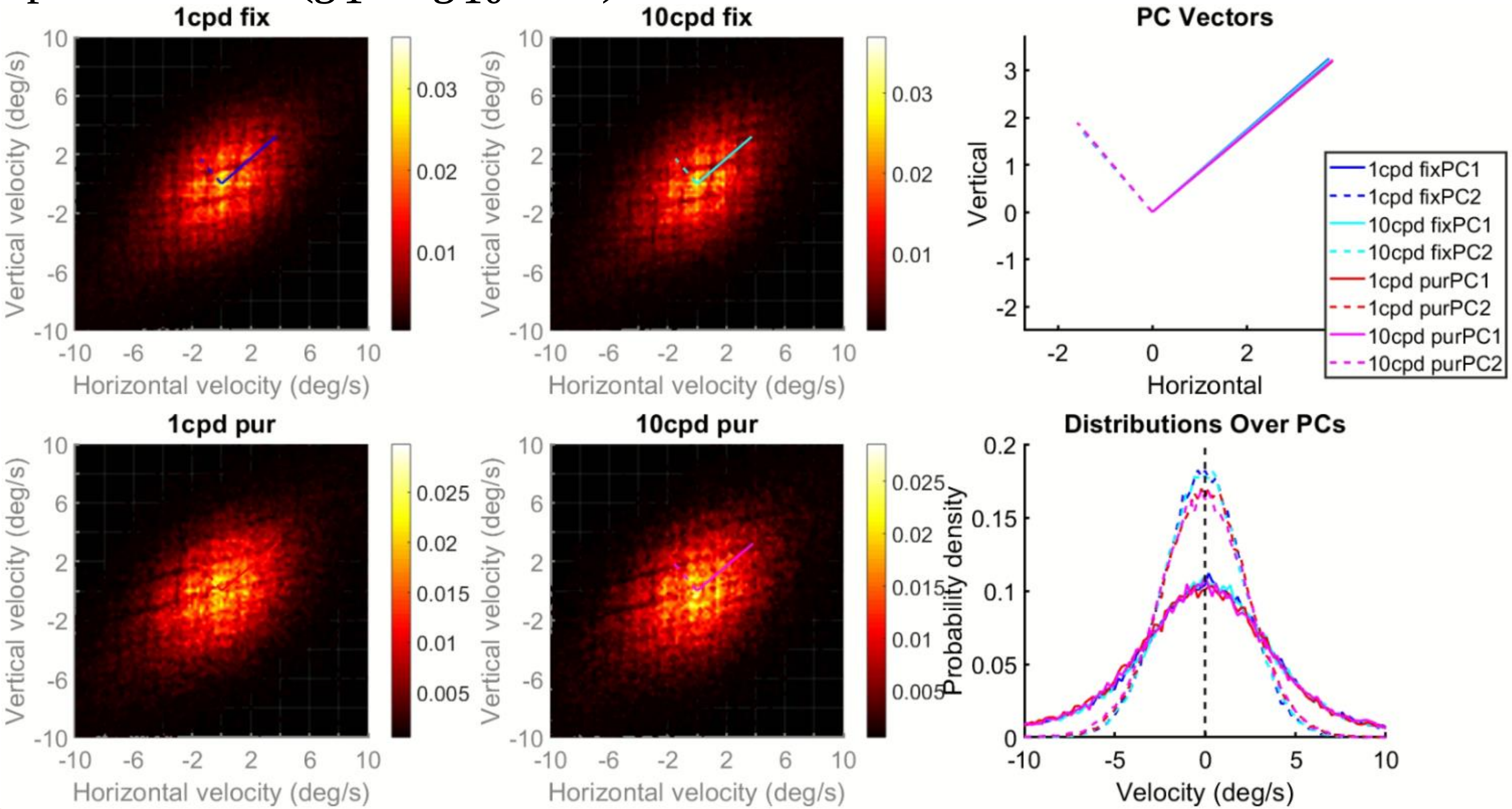


Band Noise Target

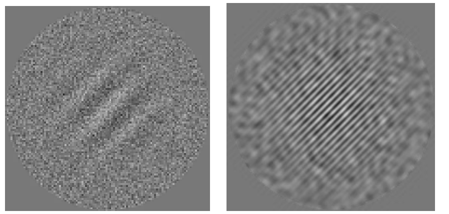
Drift Velocity Distribution (**Relative**): Band Noise Target

➢ Wider in pursuit trials ($g_1 < g_{10} \approx 1$)

A016



❖ Preliminary Experiments & Data: Drifts

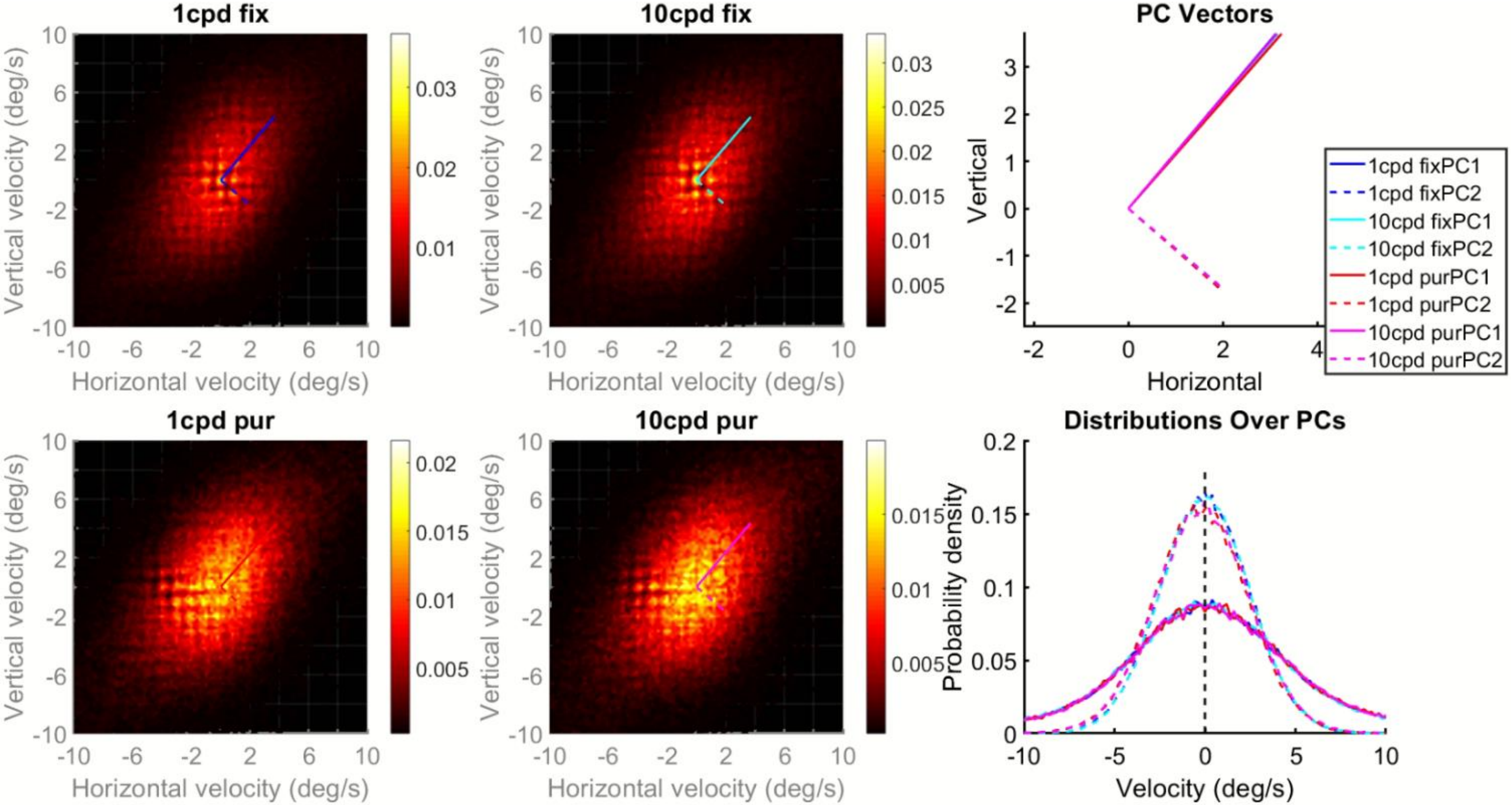


Band Noise Target

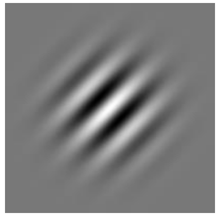
Drift Velocity Distribution (**Relative**): Band Noise Target

➢ Wider in pursuit trials ($g_1 < g_{10} < 1$)

Bin



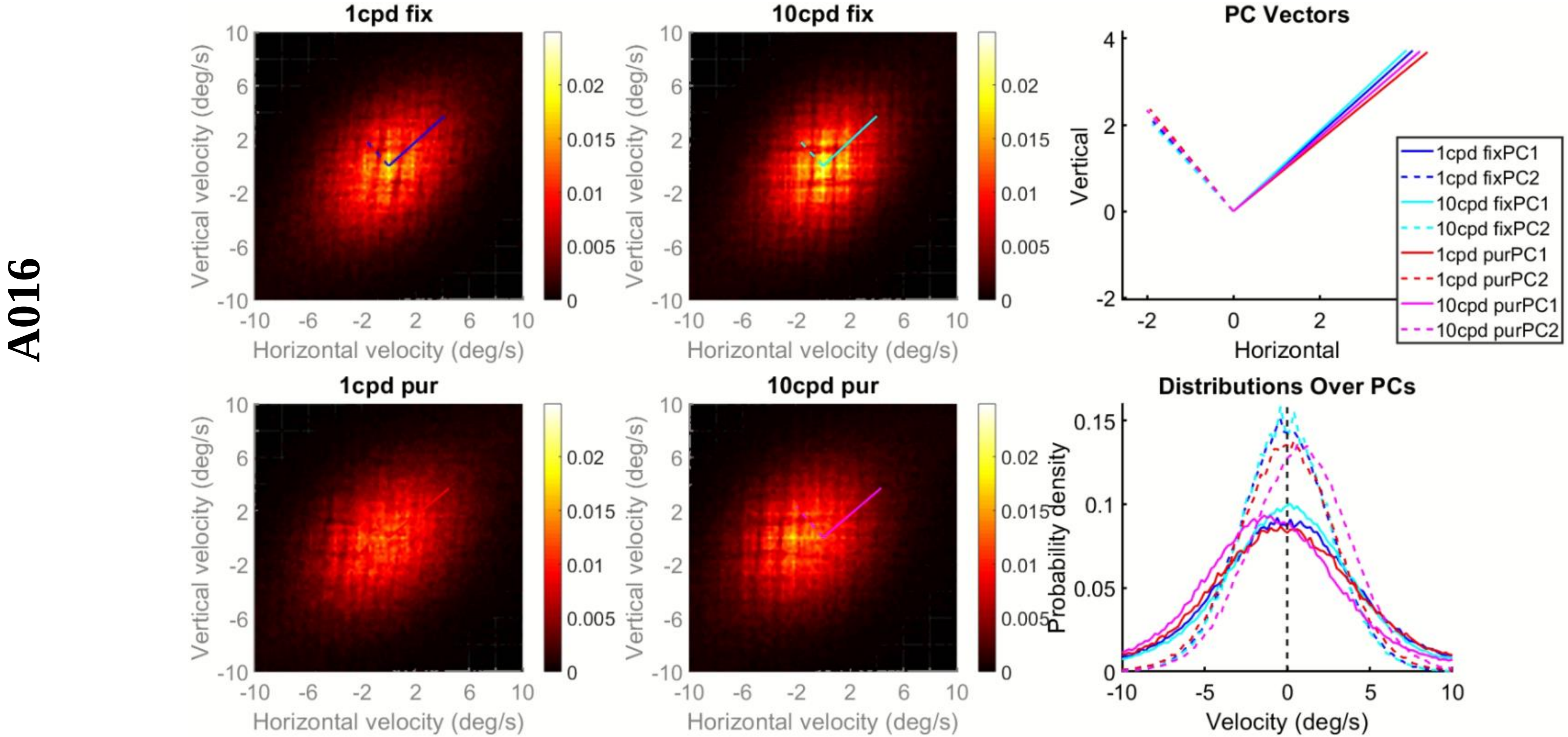
❖ Preliminary Experiments & Data: Drifts



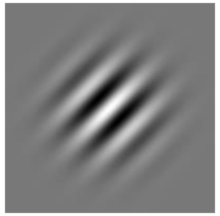
No Noise | Full Contrast

Drift Velocity Distribution (**Relative**): No Noise | Full Contrast

➢ Wider and **left shift** in pursuit trials ($g_{10} < g_1 < 1$)



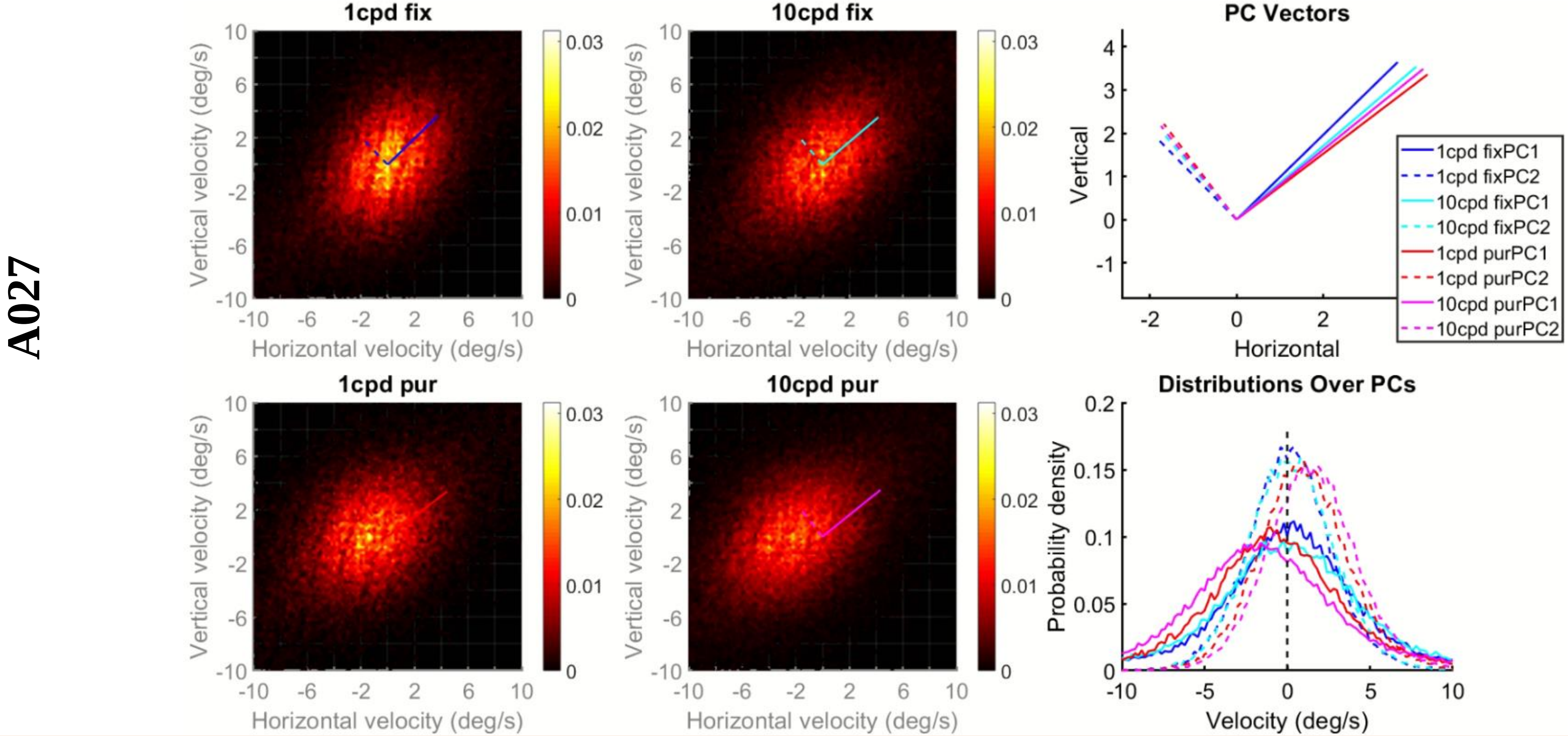
❖ Preliminary Experiments & Data: Drifts



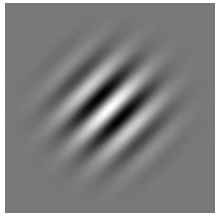
No Noise | Full Contrast

Drift Velocity Distribution (**Relative**): No Noise | Full Contrast

➢ Wider and **left shift** in pursuit trials ($g_{10} < g_1 < 1$)



❖ Preliminary Experiments & Data: Drifts

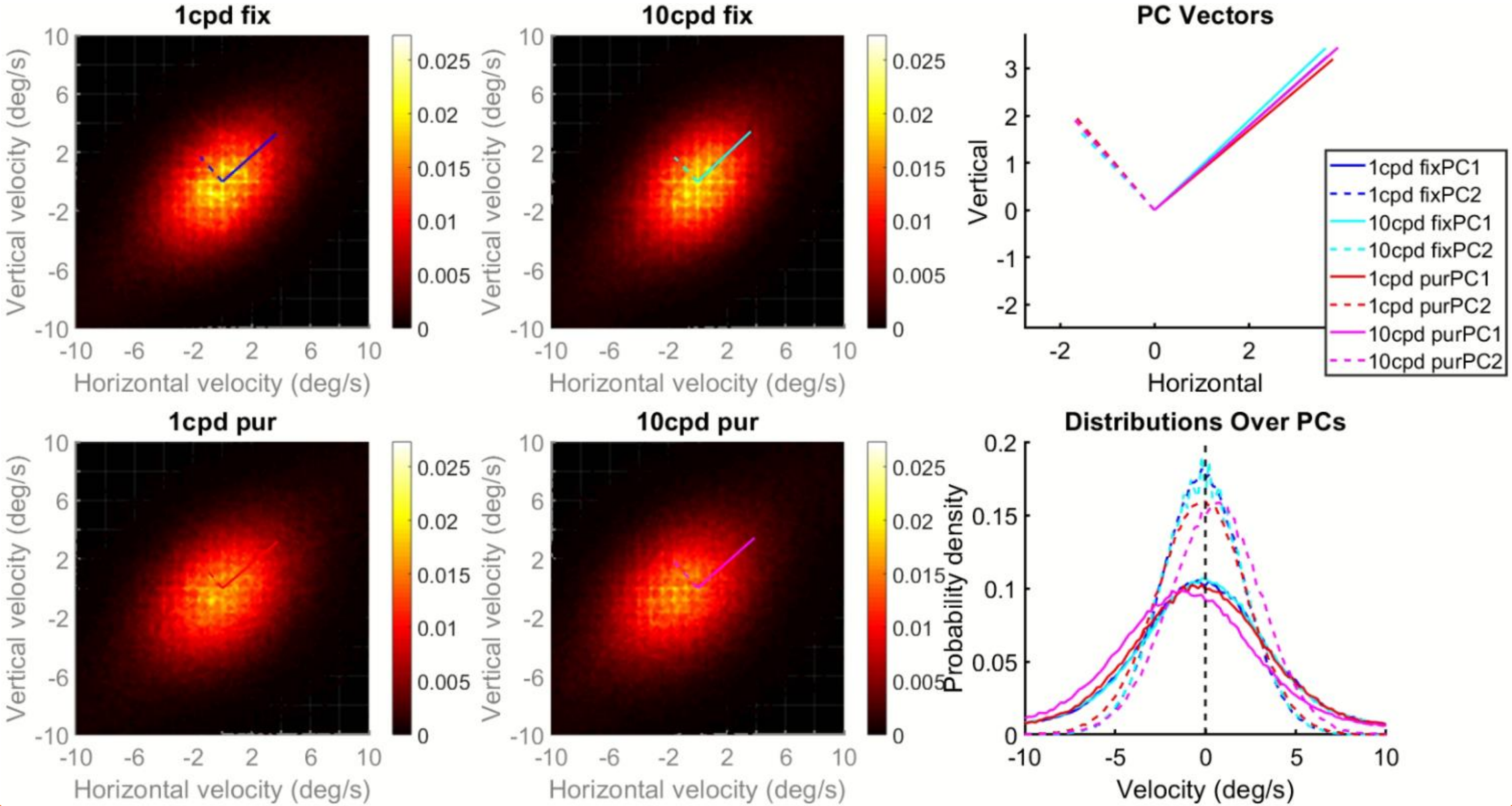


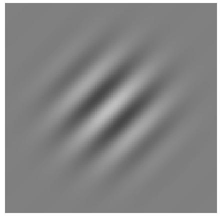
No Noise | Full Contrast

Drift Velocity Distribution (**Relative**): No Noise | Full Contrast

- Wider and **left shift** in pursuit trials ($g_{10} < g_1 < 1$)

A056





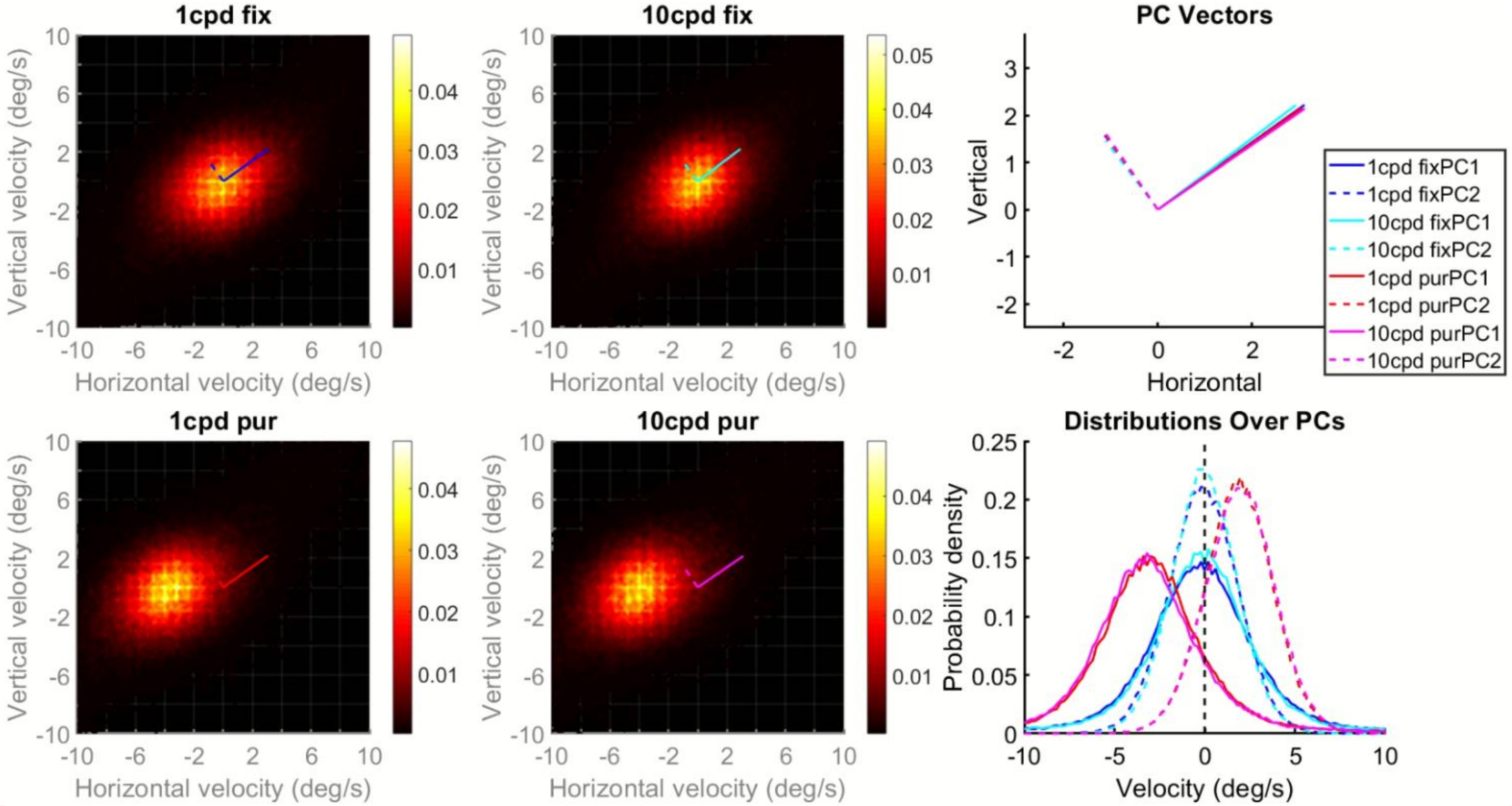
❖ Preliminary Experiments & Data: Drifts

No Noise | Contrast 90%

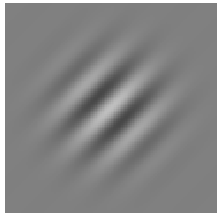
Drift Velocity Distribution (**Relative**): No Noise | Contrast at 90%

- Wider (10cpd) and **left shift** in pursuit trials ($g_{10} < g_1 \ll 1$)

A081



❖ Preliminary Experiments & Data: Drifts

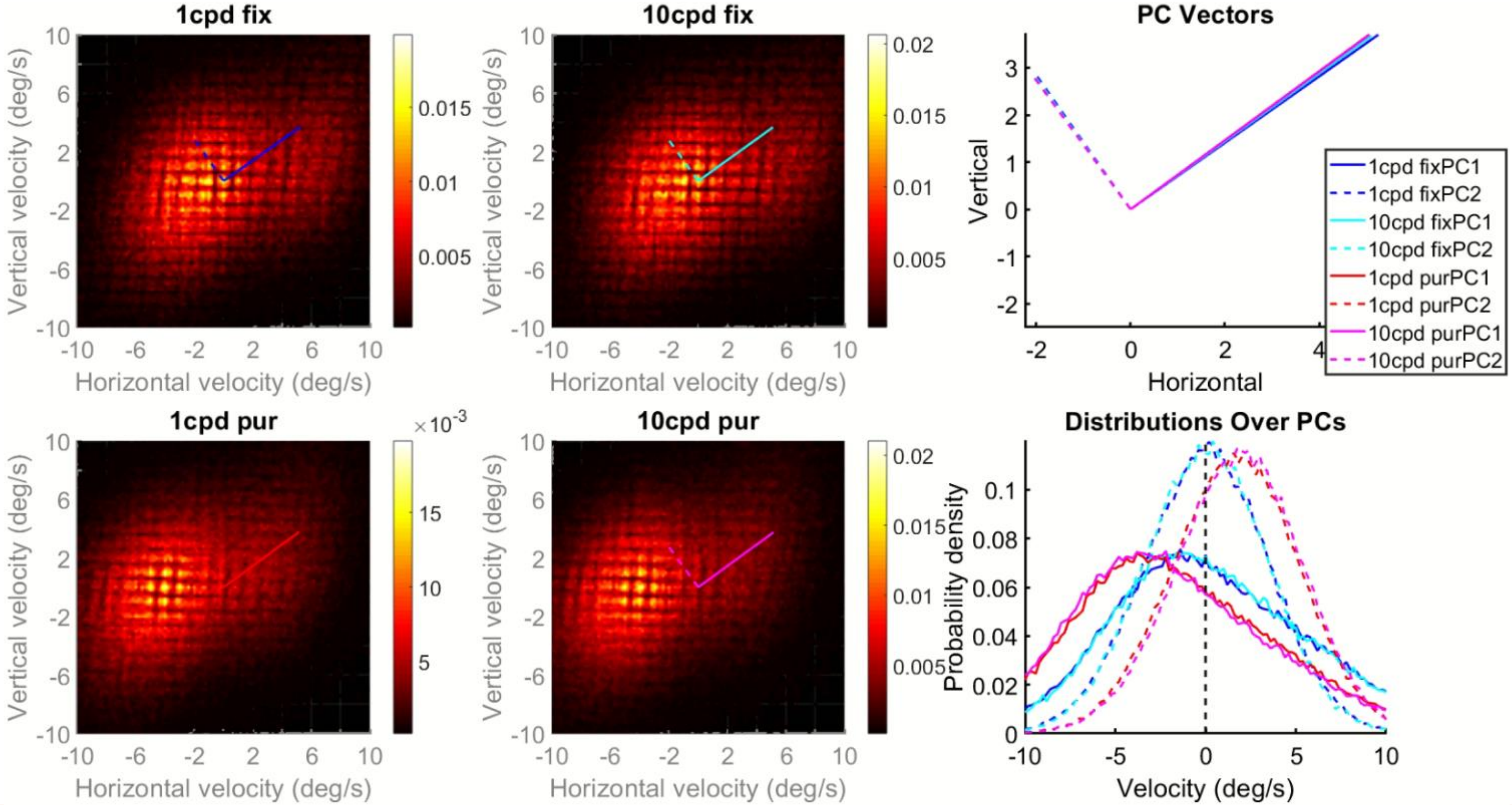


No Noise | Contrast 90%

Drift Velocity Distribution (**Relative**): No Noise | Contrast at 90%

➢ **Left shift** in pursuit trials, and **bi-modal distribution** ($g_{10} < g_1 \ll 1$)

Bin



❖ Preliminary Experiments & Data: EMs

Interim Summary

- Eye drifting velocity (relative to target) distribution was either more diffused (when pursuit gain slightly below 1, significant **or not**) or shifted to the left (when pursuit gain substantially below 1) in pursuit trials

OUTLINE

- Background
  - Eye Movement Patterns During Smooth Pursuit
  - Visual Sensitivity during Smooth Pursuit
    - Retinal Effect
    - Non-retinal Effect
  - Summary & Scientific Questions
- **Preliminary Experiments & Data**
  - Characterize Pursuit EMs: pursuit gain, pos dist, vel dist
  - **Factor Analysis**
- Brain Storming

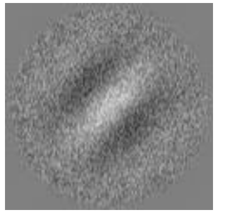
❖ Preliminary Experiments & Data: Factor Analysis

Natural Noise Target

SF	Subject	Statistics	Contrast	Pursuit	Gain	DF	DF Detrend	Total Bias	Drift Speed	nMascs	nSacs	nMacs+nSacs	Drift PSD
1 cpd	A025	*N*	369	369	369	369	369	369	363	369	369	369	369
		Coefficient	0.147456	0.700769	-2.62779	0.010746	0.01861	0.068584	0.004986	-0.00856	-0.0864	0.112831	0.147456
		p-value	**1.91E-09**	**0.013623**	0.455986	**0.001136**	0.088073	**0.004442**	0.479217	0.909186	0.336926	0.314671	**1.91E-09**
	A049 (5°/s)	*N*	583	583	583	583	583	583	582	583	583	583	583
		Coefficient	0.133926	-0.00829	0.038608	-0.00118	-0.02532	-0.02193	-0.00368	0.299463	0.105694	0.279228	0.133926
		p-value	**1.44E-07**	0.964732	0.993424	0.088403	0.068313	0.066821	0.789066	**0.006265**	0.365196	**0.028184**	**1.44E-07**
	A049 (4°/s)	*N*	899	899	899	899	899	899	899	899	899	899	899
		Coefficient	0.148607	0.164403	1.312063	0.002167	0.023264	0.016428	0.017735	0.02073	0.078361	-0.03763	0.148607
		p-value	**1.90E-09**	0.292612	0.628015	**0.030107**	0.130111	0.080797	**0.031123**	0.802825	0.426627	0.660928	**1.90E-09**
10 cpd	A025	*N*	392	392	392	392	392	392	391	392	392	392	392
		Coefficient	0.08143	0.46227	0.778721	-0.00017	0.000826	-0.00664	0.018459	0.050371	0.012136	0.04143	0.08143
		p-value	**0.004233**	0.06542	0.640916	0.326167	0.632951	0.333433	**0.050066**	0.696964	0.911813	0.773164	**0.004233**
	A049 (5°/s)	*N*	313	313	313	313	313	313	308	313	313	313	313
		Coefficient	0.71959	-0.17192	0.832218	0.000397	-0.00113	0.005504	-0.00303	-0.00526	0.054153	-0.07405	0.71959
		p-value	**7.66E-11**	0.540638	0.867594	0.789369	0.962531	0.714078	0.794328	0.970543	0.72957	0.668449	**7.66E-11**
	A049 (4°/s)	*N*	730	730	730	730	730	730	729	730	730	730	730
		Coefficient	0.691303	0.077027	3.231558	-0.00016	-0.02096	0.003167	-0.00569	-0.05852	-0.04415	-0.02272	0.691303
		p-value	**0**	0.686797	0.358304	0.920958	0.156467	0.804639	0.629396	0.625055	0.738154	0.850989	**0**

A025: $g_1 < g_{10} < 1$; A049: $g_{10} < g_1 < 1$; A049(4deg): $g_1 \approx g_{10} \approx 1$

❖ Preliminary Experiments & Data: Factor Analysis

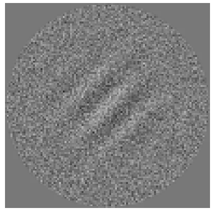


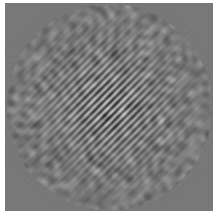
White Noise Target

SF	Subject	Statistics	Contrast	Pursuit	Gain	DF	DF Detrend	Total Bias	Drift Speed	nMascs	nSacs	nMacs+nSacs	Drift PSD
1 cpd	A016	*N*	80	80	80	80	80	80	80	80	80	80	80
		Coefficient	1.04E-01	-0.034	2.7787	-0.011	-0.063	-0.055	-0.022	0.2147	-0.416	0.6634	-0.01
		p-value	**1.29E-06**	0.9576	0.7893	0.2314	0.1621	0.4346	0.4432	0.436	0.2501	**5.15E-02**	0.6964
	Bin	*N*	176	176	176	176	176	176	171	176	176	176	176
		Coefficient	2.03E-01	-0.383	3.1755	-0.002	-0.073	-0.02	-0.035	-0.245	-0.221	-0.9354	-0.016
		p-value	**5.85E-13**	0.3604	0.5037	**0.0451**	**0.0069**	0.1048	**0.0106**	0.1458	0.1941	0.32388	**0.0408**
10 cpd	A016	*N*	70	70	70	70	70	70	70	70	70	70	70
		Coefficient	1.45008	-0.486	1.335	0.0028	-0.008	0.0442	-0.006	-0.384	-0.524	-0.2668	0.0584
		p-value	**8.53E-06**	0.4608	0.8545	0.2715	0.8334	0.2288	0.8394	0.1408	0.2522	0.35246	0.6423
	Bin	*N*	158	158	158	158	158	158	154	158	158	158	158
		Coefficient	1.03E-01	0.2774	3.4099	0.001	0.043	0.0054	0.0028	0.2623	0.1668	1.93336	-0.159
		p-value	**5.12E-14**	0.5358	0.581	0.4412	0.3316	0.6914	0.8926	0.3538	0.5611	0.1148	**0.0313**

A016: $g_1 \approx g_{10} < 1$; Bin: $g_1 \approx g_{10} > 1$

❖ Preliminary Experiments & Data: Factor Analysis



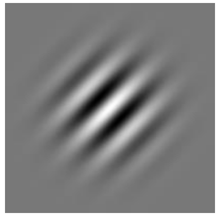


Band Noise Target

SF	Subject	Statistics	Contrast	Pursuit	Gain	DF	DF Detrend	Total Bias	Drift Speed	nMascs	nSacs	nMacs+nSacs	Drift PSD
1 cpd	A016	*N*	94	94	94	94	94	94	94	94	94	94	94
		Coefficient	2.23E-01	-0.382	7.9707	0.0035	0.0395	-0.006	-0.032	0.3253	0.4313	0.11174	0.0097
		p-value	**5.01E-05**	0.4811	0.2048	0.5652	0.5236	0.9115	0.2093	0.1623	0.1948	0.62646	0.607
	Bin	*N*	194	194	194	194	194	194	188	194	194	194	194
		Coefficient	2.02E-01	0.0347	-1.583	-0.001	0.0096	-0.01	-0.006	0.1826	0.1375	1.33009	0.0004
		p-value	**2.78E-04**	0.9181	0.708	0.3145	0.6966	0.4633	0.6682	0.1958	0.3353	0.07524	0.9588
10 cpd	A016	*N*	88	88	88	88	88	88	88	88	88	88	88
		Coefficient	0.37568	0.3094	4.2115	0.0062	0.0363	0.0478	0.0171	0.235	-0.081	0.30564	-0.064
		p-value	**4.76E-04**	0.5987	0.5257	0.3261	0.6578	0.3431	0.5733	0.3005	0.7679	0.19638	0.5207
	Bin	*N*	194	194	194	194	194	194	187	194	194	194	194
		Coefficient	1.370409	-0.213	-4.54	-7E-04	0.0027	-0.007	-4E-04	0.0471	0.0431	0.28512	-0.006
		p-value	**6.00E-09**	0.5494	0.3878	0.7047	0.8263	0.6655	0.9746	0.7459	0.7712	0.78327	0.934

A016: $g_1 < g_{10} \approx 1$; Bin: $g_1 < g_{10} < 1$

❖ Preliminary Experiments & Data: Factor Analysis

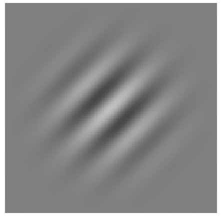


No Noise | Full Contrast

SF	Subject	Statistics	Pursuit	Gain	DF	DF Detrend	Total Bias	Drift Speed	nMascs	nSacs	nMacs+nSacs	Drift PSD
1 cpd	A056	*N*	286	286	286	286	286	285	286	286	286	286
		Coefficient	-0.18625	-3.38094	0.001874	0.013879	0.006803	-0.01534	0.13271	0.276255	-0.08804	0.008914
		p-value	0.821566	0.662174	0.501966	0.573357	0.814327	0.588448	0.606794	0.373344	0.763321	0.645561
	A016	*N*	227	227	227	227	227	227	227	227	227	227
		Coefficient	-97.9313	4.506059	0.010387	-0.0286	0.128339	0.030109	0.19209	-0.43226	0.635675	0.038693
		p-value	0.21074	0.793611	0.752094	0.563231	0.563436	0.792693	0.7659	0.505678	0.378826	0.634492
	A027	*N*	46	46	46	46	46	45	46	46	46	45
		Coefficient	1.78E-13	7.73E-13	-2.58E-16	-4.12E-16	4.40E-15	-5.86E-15	1.69E-14	-5.87E-14	-1.95E-14	-6.34E-15
		p-value	1	1	1	1	1	1	1	1	1	1
10 cpd	A056	*N*	315	315	315	315	315	314	315	315	315	315
		Coefficient	0.35667	-2.41735	0.001713	0.010709	0.00213	0.012061	-0.1912	-0.53494	0.206409	-0.07941
		p-value	0.767998	0.490907	0.216833	0.699757	0.901447	0.581051	0.579664	0.169789	0.584649	0.499248
	A016	*N*	256	256	256	256	256	251	256	256	256	256
		Coefficient	-97.8476	4.812093	-0.00029	0.042122	-0.01349	-0.03895	-0.69752	52.08134	-1.49262	0.299153
		p-value	0.200251	0.300748	0.720318	0.522191	0.461859	0.154192	0.221961	0.149656	**0.042289**	0.251679
	A027	*N*	60	60	60	60	60	59	60	60	60	60
		Coefficient	-0.44629	1.911199	-0.00011	0.003886	0.00065	-0.01133	0.09646	54.23402	0.067253	0.070655
		p-value	0.7166	0.387512	0.738195	0.696042	0.956263	0.459441	0.59426	0.166108	0.740554	0.597353

$g_{10} < g_1 < 1$

❖ Preliminary Experiments & Data: Factor Analysis



No Noise | Contrast 90%

SF	Subject	Statistics	Pursuit	Gain	DF	DF Detrend	Total Bias	Drift Speed	nMascs	nSacs	nMacs+nSacs	Drift PSD
1 cpd	Bin	*N*	169	169	169	169	169	158	169	169	169	169
		Coefficient	2.51568	-3.90727	0.00044	0.128705	0.018132	0.02308	0.12975	-0.19259	0.681473	0.01865
		p-value	**1.08E-09**	**7.22E-09**	**7.21E-06**	**1.33E-07**	**2.33E-07**	**8.28E-08**	0.17800	**0.01266**	**1.08E-07**	**3.57E-09**
	A081	*N*	124	124	124	124	124	114	124	124	124	124
		Coefficient	1.65122	-1.94843	0.00021	0.021674	0.010226	0.00744	-0.0893	-0.41985	-0.06891	0.01412
		p-value	**0.00061**	**0.001345**	**0.00159**	0.22038	**0.000607**	**0.01824**	0.54416	0.479943	0.652479	**0.000251**
10 cpd	Bin	*N*	171	171	171	171	171	154	171	171	171	171
		Coefficient	-100.4	16.84288	-0.0005	0.000408	-0.01939	-0.0095	-0.1795	0.079058	-0.52989	1.446257
		p-value	**0.00059**	**3.87E-06**	**1.47E-04**	0.969623	**0.000411**	0.11401	0.14826	0.645508	**0.00919**	**8.55E-06**
	A081	*N*	118	118	118	118	118	105	118	118	118	118
		Coefficient	-100.89	6.795836	-0.0002	-0.00266	-0.00988	-0.0059	-0.3516	-0.38852	-0.34407	2.029419
		p-value	**0.00019**	**2.41E-05**	**0.0024**	0.647569	**0.009638**	0.36231	0.09324	0.612202	0.110012	**1.57E-05**

$g_{10} < g_{11} \ll 1$

❖ Preliminary Experiments & Data: Factor Analysis

Interim Summary

- When there is a noise patch, the weighted total temporal power only shows positive effect on performance with the natural noise
- No other factors show consistent / significant effect
  - Kind of surprising, as DF and temporal power are always higher for pursuit
  - Probably due to:
    - Too small variance in predictors, especially within fixation (or pursuit) trials
    - Power of noise patch is also modulated (but band noise should work?)
- For the condition with no noise patch and contrast @ 90%, lots of factors affect performance
  - Should be due to that these predictors are correlated with each other
  - Such effect is not so novel considering the literature

❖ Preliminary Experiments & Data: EMs

Interim Summary

- Drift diffusion coefficient was always higher in pursuit trials

- No consistent difference in drift diffusion coefficient between 1 cpd and 10 cpd in pursuit trials; except for the Band Noise Background condition, which could be explained by the difference in pursuit gain

- The lower the pursuit gain, the more the catch-up saccades

OUTLINE

- **Background**
  - **Eye Movement Patterns During Smooth Pursuit**
  - **Visual Sensitivity during Smooth Pursuit**
    - **Retinal Effect**
    - **Non-retinal Effect**
  - **Summary & Scientific Questions**
- **Preliminary Experiments & Data**
  - **Characterize Pursuit EMs: pursuit gain, pos dist, vel dist**
  - **Factor Analysis**
- **Brain Storming**

❖ Brain Storming

➢ **For perfect pursuit, how does retinal motion (caused by drift-like component) affect visual sensitivity for different spatial frequencies?**

Expectation:

- The more the retinal motion, the higher sensitivity to low SF and lower sensitivity to high SF (This is opposite to non-retinal effects, therefore might difficult to observe)

Experiment:

Circle/target + Gabor/stimulus (noise background causes problem in terms of SNR; band noise causes problem in control of pursuit gain)

- Seems pursuit always has higher DF, we could simply compare pursuit and fixation
- Orientation discrimination: **stabilize** the Gabor, hopefully the motion is not obvious
- Detection task: **stabilize** vertically the pursuit target and a horizontally oriented Gabor

Brain Storming

- **What are the characteristics of smooth pursuit eye movements?**

pursuit component + **drift-like component**

Evidence:

- Fixation was 0-velocity "smooth pursuit" (Steinman 1990); more careful literature review was required to confirm this question was not already investigated
- Drift velocity distribution in pursuit trials looked very similar to that in fixation trials, but
  - More diffused when pursuit gain slightly below 1, significant **or not**
  - The whole distribution (relative to target) could shift if pursuit gain substantially below 1

Other analysis methods?

OUTLINE

THANKS

OUTLINE

- Background
  - Eye Movement Patterns During Smooth Pursuit
  - Visual Sensitivity during Smooth Pursuit
    - Retinal Effect
    - Non-retinal Effect
  - Summary & Scientific Questions
- Preliminary Experiments & Data
  - Characterize Pursuit EMs: pursuit gain, pos dist, vel dist, drift segment dist
  - Factor Analysis
- Brain Storming
- **Supplementary**

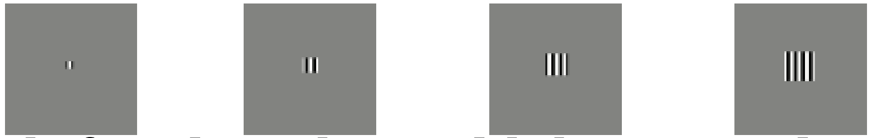
❖ Brain Storming

- **Is pursuit gain / catch-up saccades rate modulated / actively controlled to enhance sensitivity depending on spatial frequency?**
  - **Prediction**: higher SF => faster pursuit & less saccades; Vice versa.
  - **Difficulties:**
    - Pursuit gain & catch-up saccade rate are strongly modulated by motion estimation
    - Other factors related to SF already investigated?
    - Pursuit gain & catch-up saccades also change retinal location, any confounding issue?
  - **Experiment:**
    - Control the contrast for equal motion estimation across SFs
  - Note that the perceptual effect of pursuit gain is less novel, considering the literature available.

- **Difference in contrast sensitivity in terms of orientation discrimination and motion detection**
  - We found difference in pursuit gain even when same contrast thresholds measured in orientation discrimination
  - Check the literature whether already investigated

❖ Brain Storming

- **For perfect pursuit, is retinal motion actively controlled for higher sensitivity to target SF?**
  - If indeed it was the case, then why we never saw such phenomenon in other conditions, e.g., fixation? (Duje asked a similar question)
  - How to differentiate from that retinal motion is merely affected by feature size? (Duje)
    - Oculomotor is spatially guided by visual input (literature?)
    - For high-acuity tasks, e.g., Snellen, it is reasonable to keep the stimulus in the PRL (the right term?) as accurate as possible, which results in smaller DF
  - Related to last point, according to Intoy & Rucci, 2020, and Intoy et. al., VSS 2020, drift is more likely to be modulated by task demands and critical feature size, instead of spatial frequency band. But how to test this?
    - Discriminate orientation of fixed-spatial-frequency grating of different sizes/cycles



    - T/L discrimination with fixed stroke width but varied size

OUTLINE

- Background
  - Eye Movement Patterns During Smooth Pursuit
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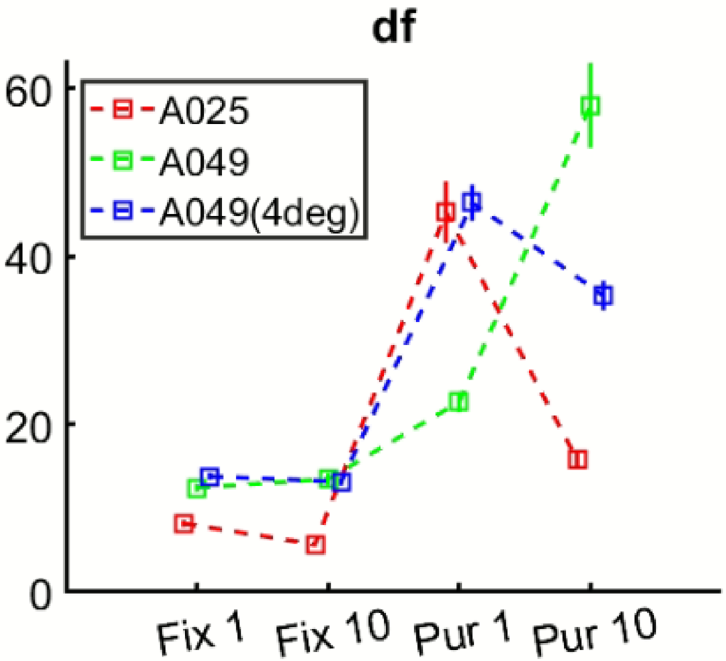
    - Retinal Effect
    - Non-retinal Effect
  - Summary & Scientific Questions
- **Preliminary Experiments & Data**
  - Drift Analysis: pursuit gain, segment dist, pos dist, vel dist
  - **Diffusion Coefficient & M/Saccade Rate**
- Brain Storming

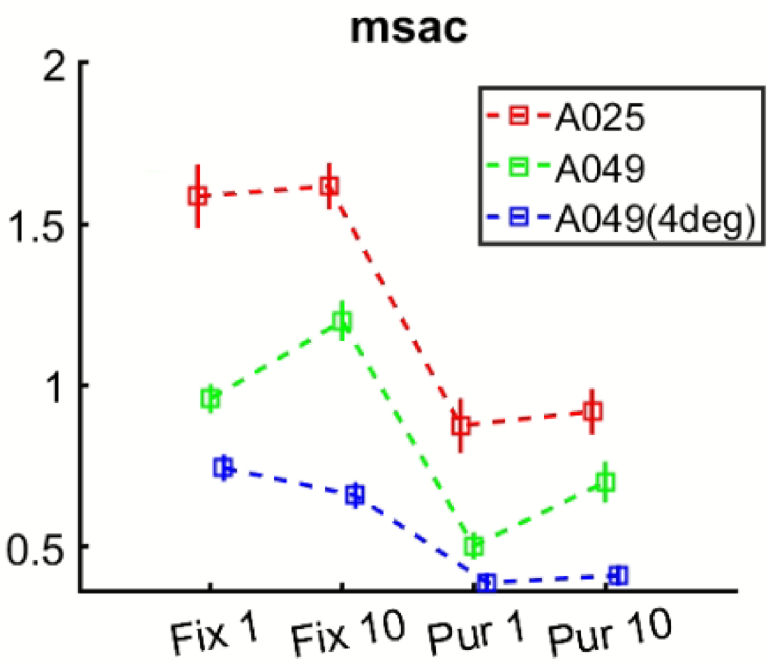
❖ Preliminary Experiments & Data: DF & Sacs

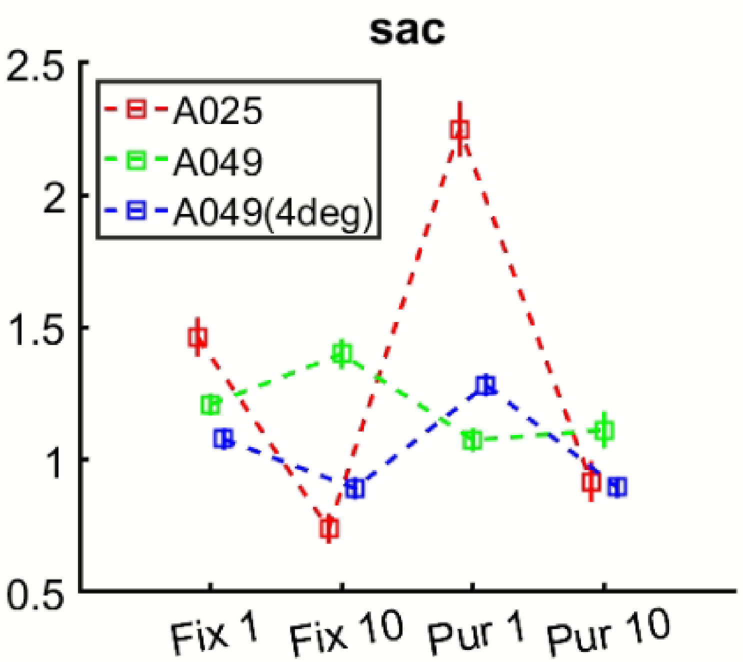
Natural Noise Target

Natural Noise Background (A025: $g_1 < g_{10} < 1$; A049: $1 > g_1 > g_{10}$; A049(4deg): $g_1 \approx g_{10} \approx 1$)

- df (diffusion coefficient):
  - Pursuit > Fixation
  - Inconsistent between 1 cpd and 10 cpd; consistent with pursuit gain (A025 and A049)
- M/Saccades:
  - More catch-up saccades when df higher







❖ Preliminary Experiments & Data: DF & Sacs

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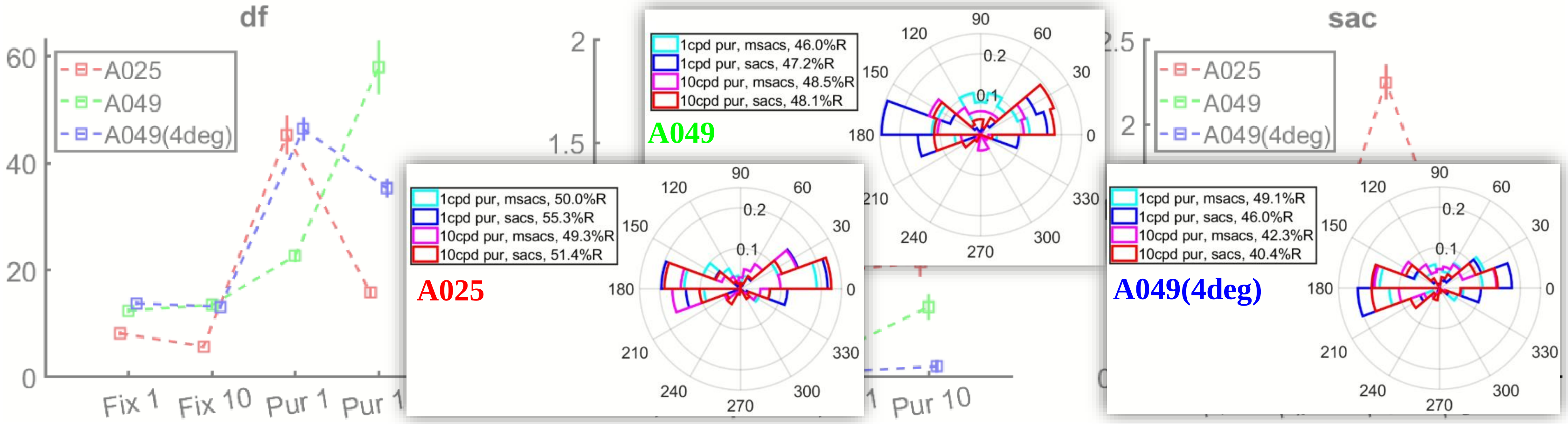
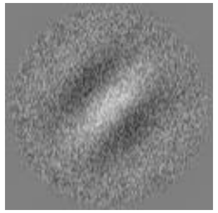


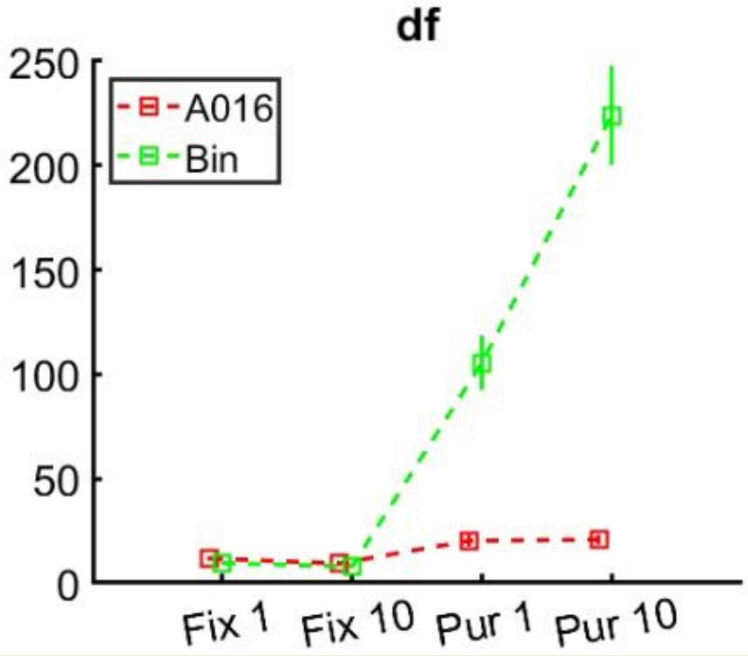
❖ Preliminary Experiments & Data: DF & Sacs

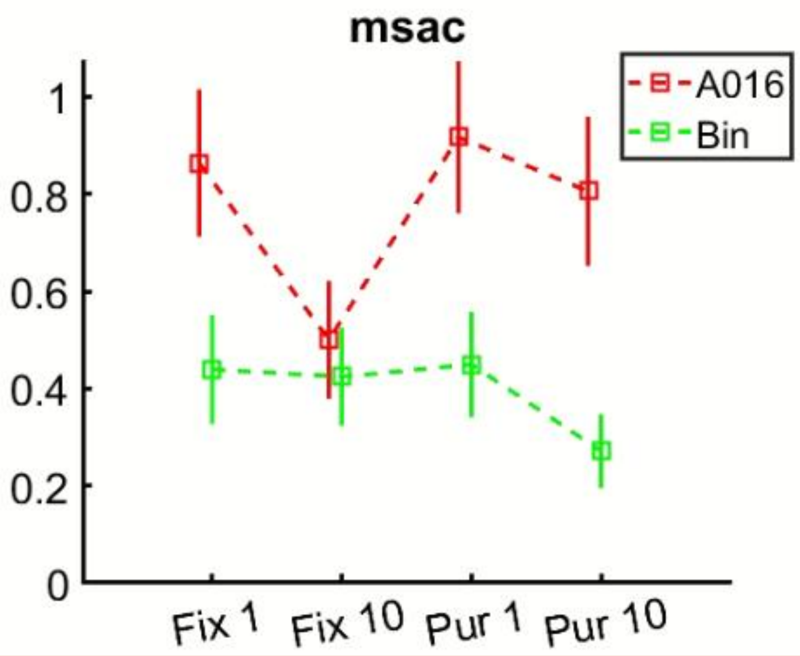


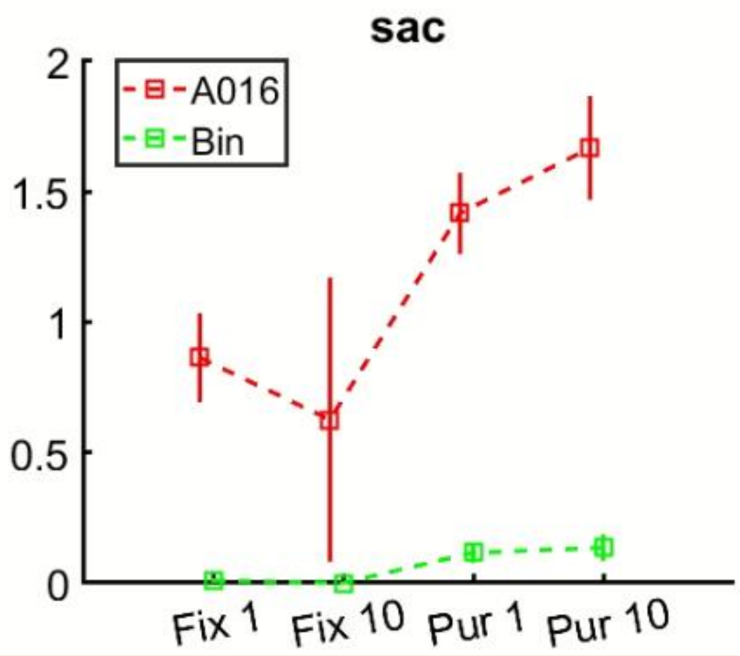
White Noise Target

White Noise Background (A016: $g_1 \approx g_{10} < 1$; Bin: $g_1 \approx g_{10} > 1$)

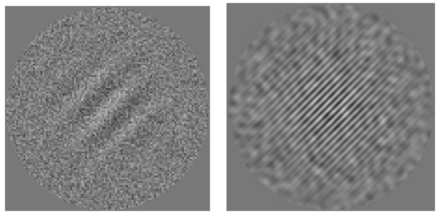
- df (diffusion coefficient):
  - Pursuit > Fixation
  - Inconsistent between 1 cpd and 10 cpd
- M/Saccades:
  - More saccades in pursuit trials







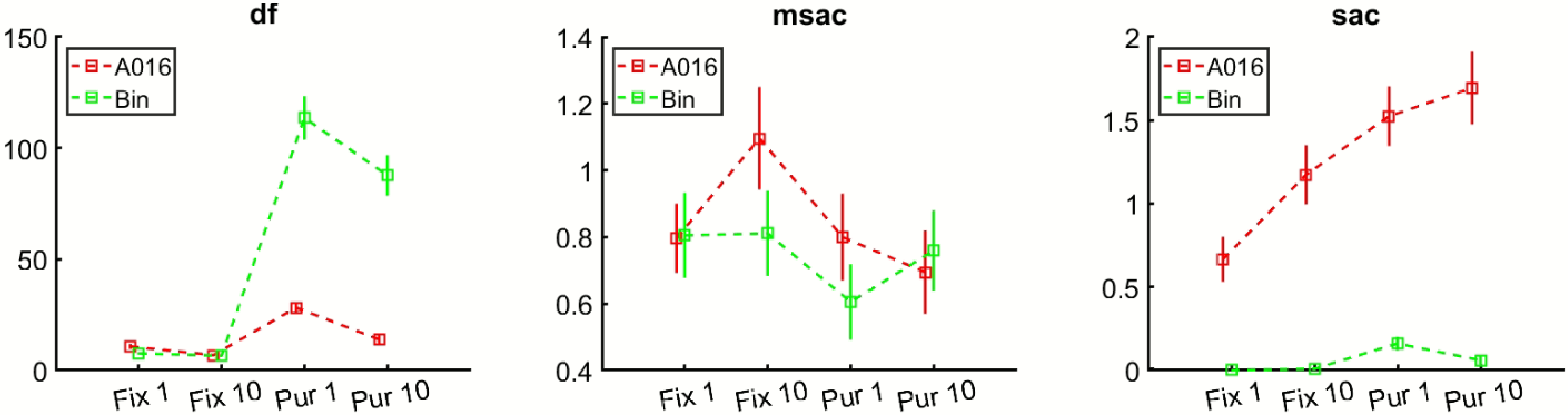
❖ Preliminary Experiments & Data: DF & Sacs



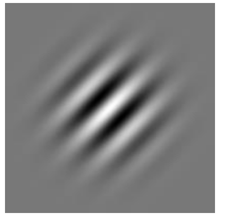
Band Noise Target

Band Noise Background (A016: $g_1 < g_{10} \approx 1$; Bin: $g_1 < g_{10} < 1$)

- df (diffusion coefficient):
  - Pursuit > Fixation
  - Difference between 1 cpd and 10 cpd is consistent with difference in pursuit gain
- M/Saccades
  - No consistent result



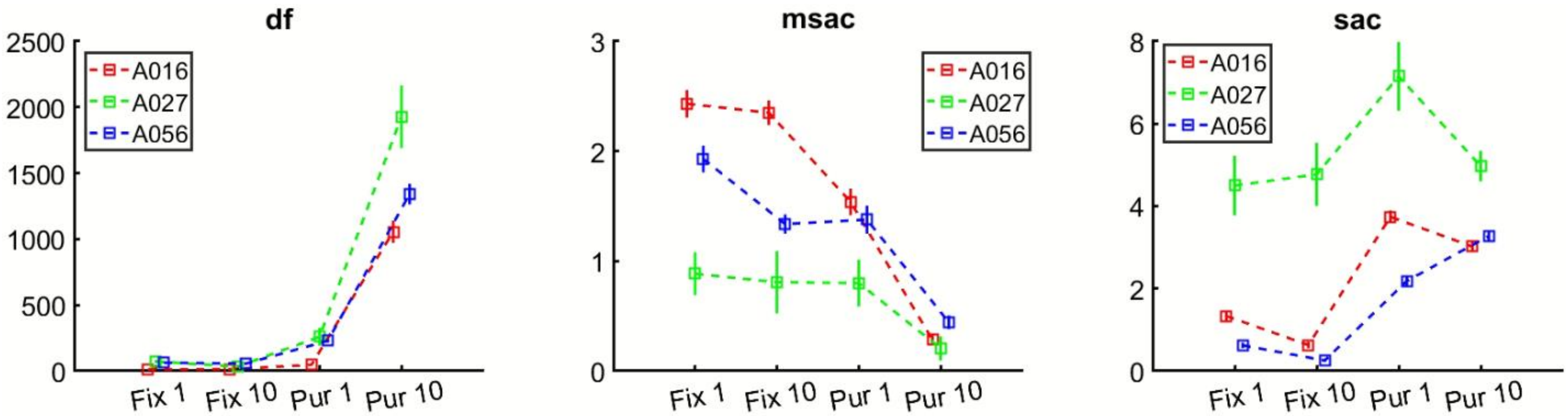
❖ Preliminary Experiments & Data: DF & Sacs



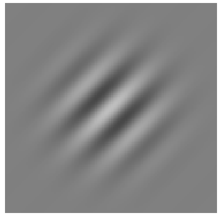
No Noise | Full Contrast

No Noise Background | Full Contrast ($g_{10} < g_1 < 1$)

- df (diffusion coefficient):
  - Pursuit > Fixation
- M/Saccades:
  - Lots of catch-up saccades in pursuit trials



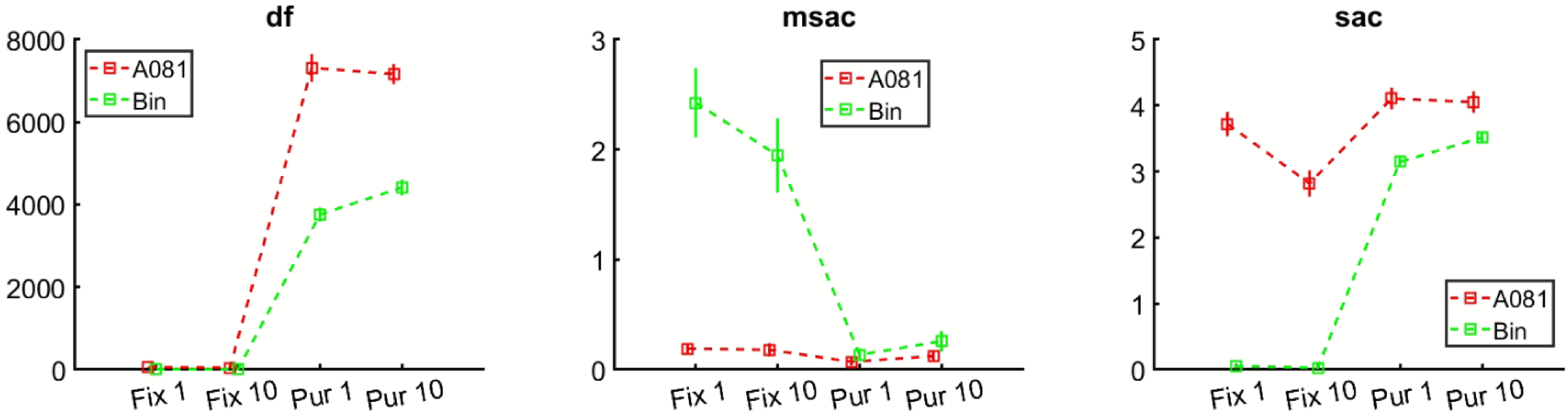
❖ Preliminary Experiments & Data: DF & Sacs



No Noise | Contrast 90%

No Noise Background | Contrast at 90% ($g_{10} < g_1 \ll 1$)

- df (diffusion coefficient):
  - Pursuit > Fixation
- M/Saccades:
  - Lots of catch-up saccades in pursuit trials



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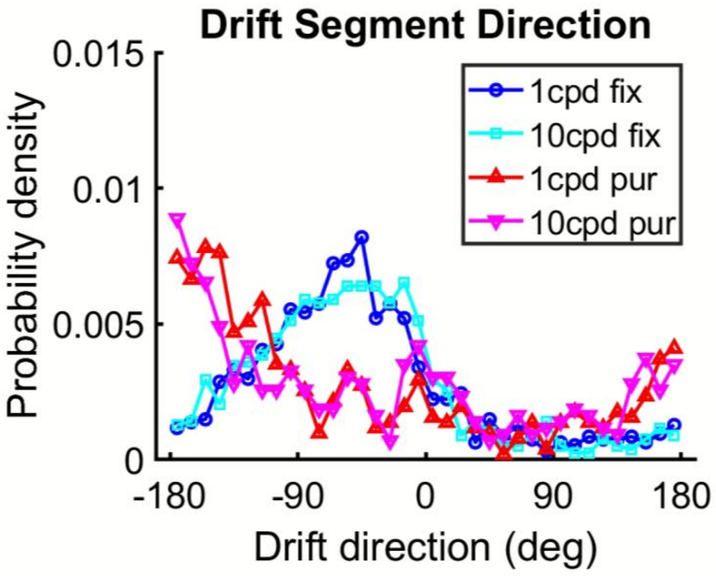
❖ Preliminary Experiments & Data: Drifts

Natural Noise Target

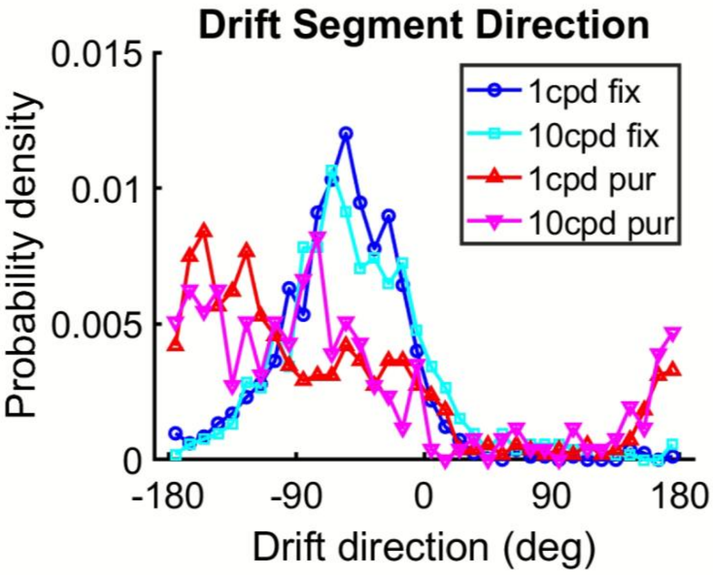
Segment Direction Distribution: Natural Noise Target

- More towards left ($\pm 180°$) in pursuit trails ($g < 1$ for A025, A049 $5°/s$)

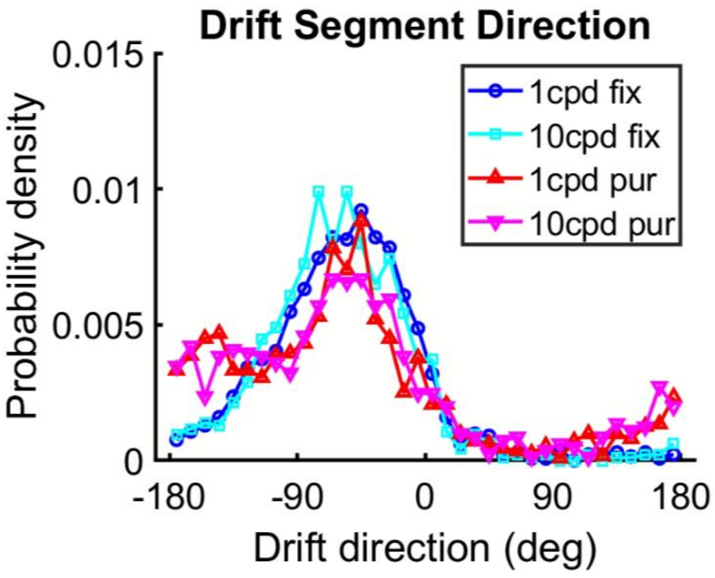
A025, $5°/s$, $g_1 < g_{10}$



A049, $5°/s$, $g_1 > g_{10}$

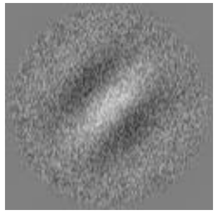


A049, $4°/s$



Although pursuit gain not significantly different from 1

❖ Preliminary Experiments & Data: Drifts

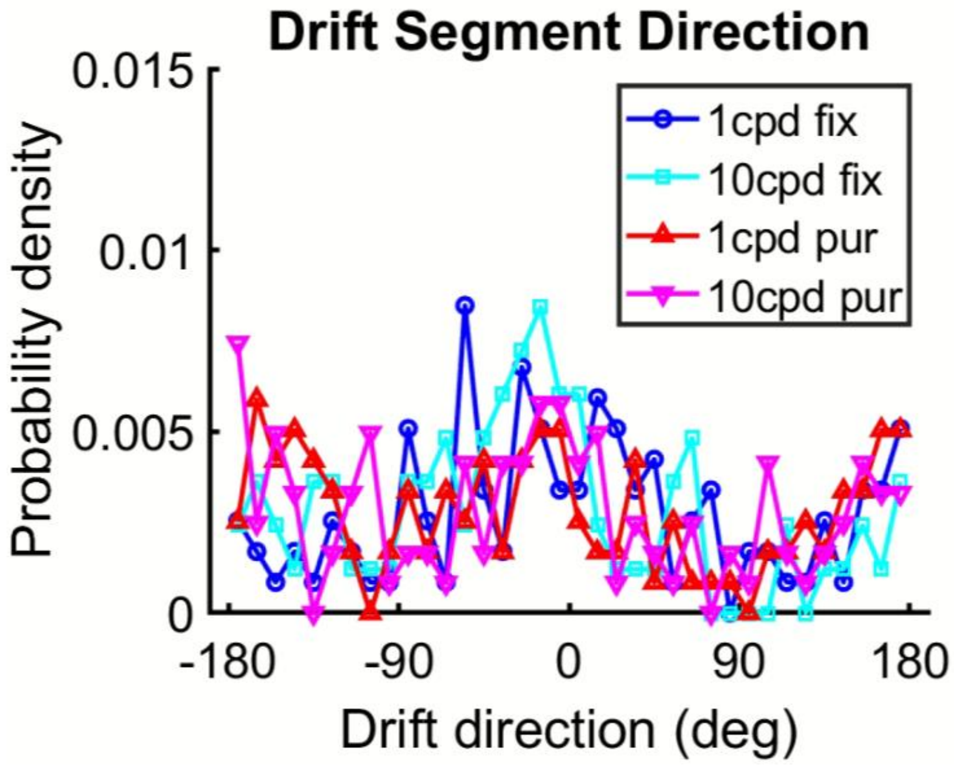


White Noise Target

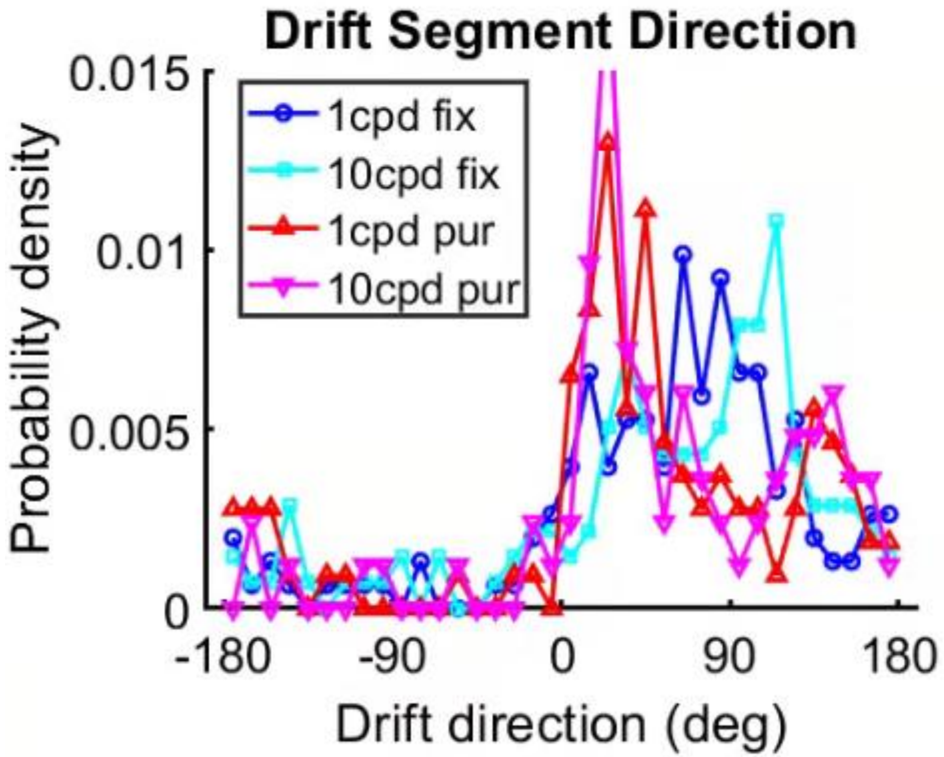
Segment Direction Distribution: White Noise Target

- A016: more towards left ($\pm 180°$) in pursuit trails ($g_1 \approx g_{10} < 1$)
- Bin: more towards right (20°) in pursuit trials ($g_1 \approx g_{10} > 1$)

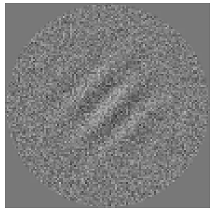
A016

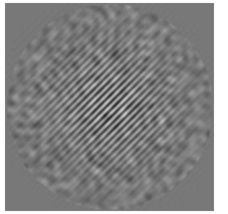


Bin



❖ Preliminary Experiments & Data: Drifts



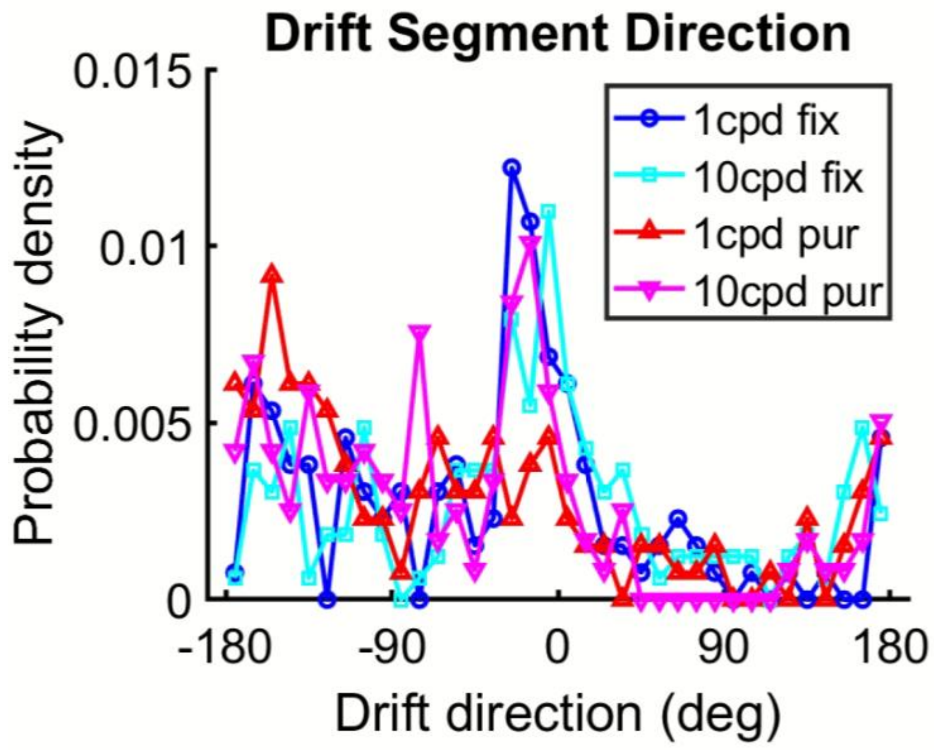


Band Noise Target

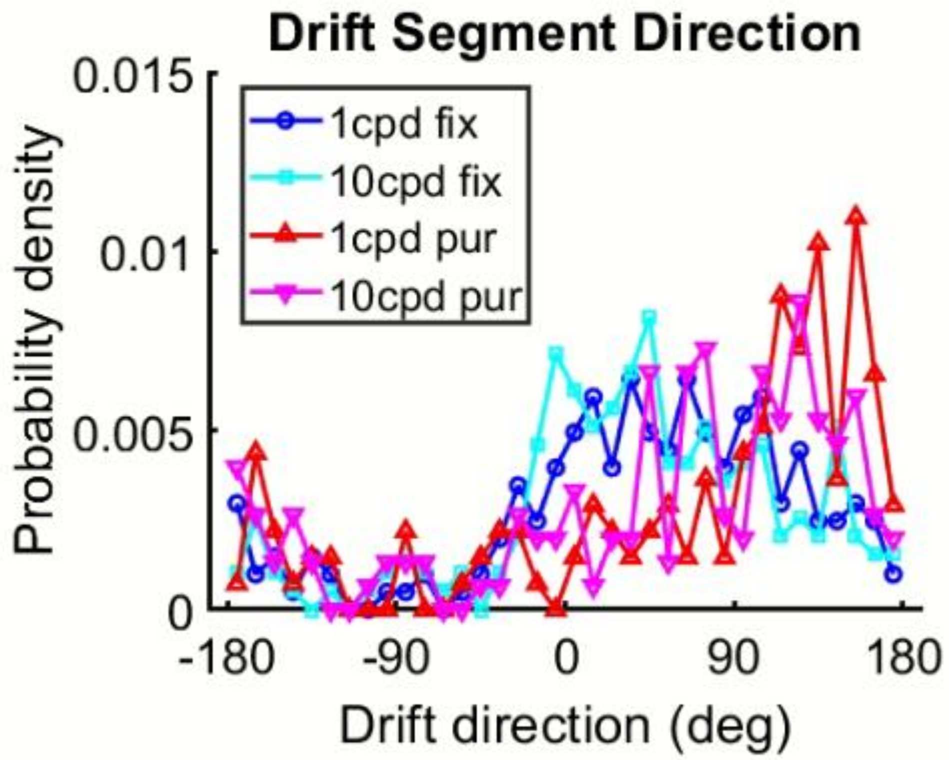
Segment Direction Distribution: Band Noise Target

- More towards left (±180°) in pursuit trails (A016: $g_1 < g_{10} \approx 1$; Bin: $g_1 < g_{10} < 1$)

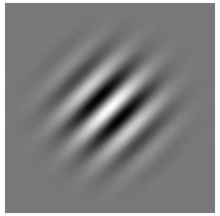
A016



Bin



❖ Preliminary Experiments & Data: Drifts

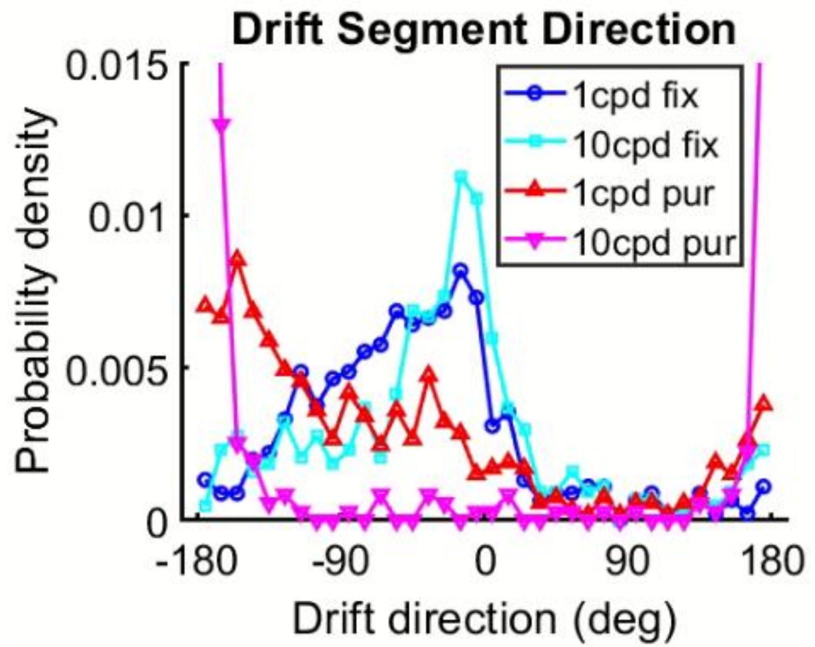


No Noise | Full Contrast

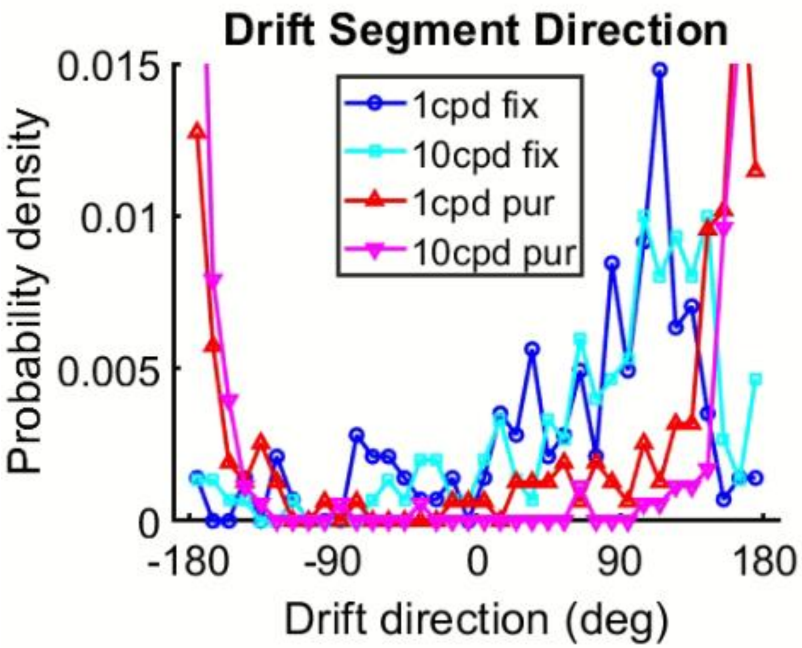
Segment Direction Distribution: No Noise | Full Contrast

➢ More towards left (±180°) in pursuit trails ($g_{10} < g_1 < 1$)

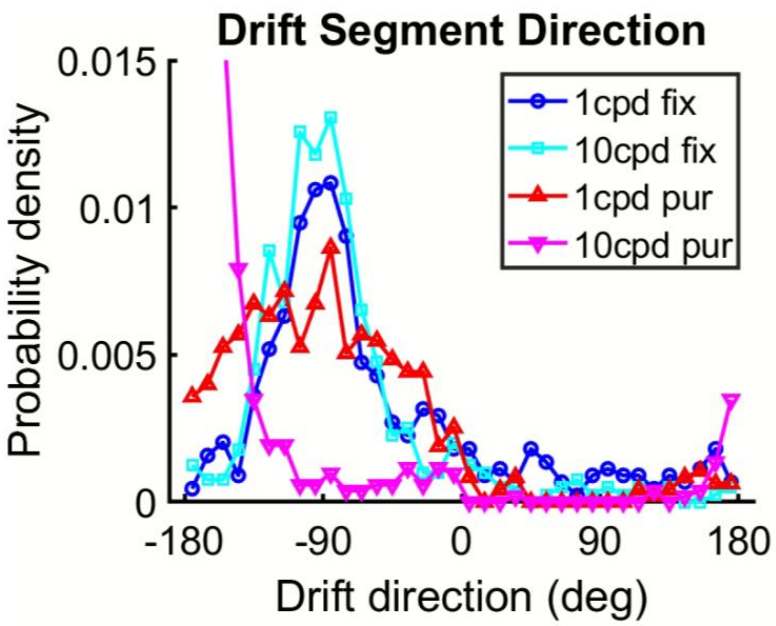
Bin



A016



A081



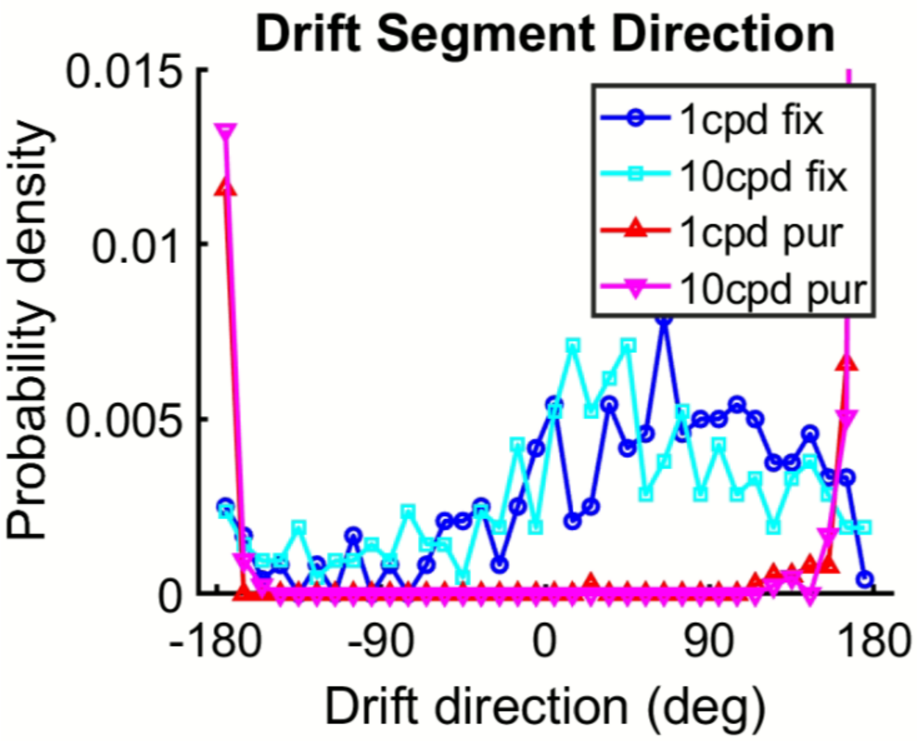
❖ Preliminary Experiments & Data: Drifts

No Noise | Contrast 90%

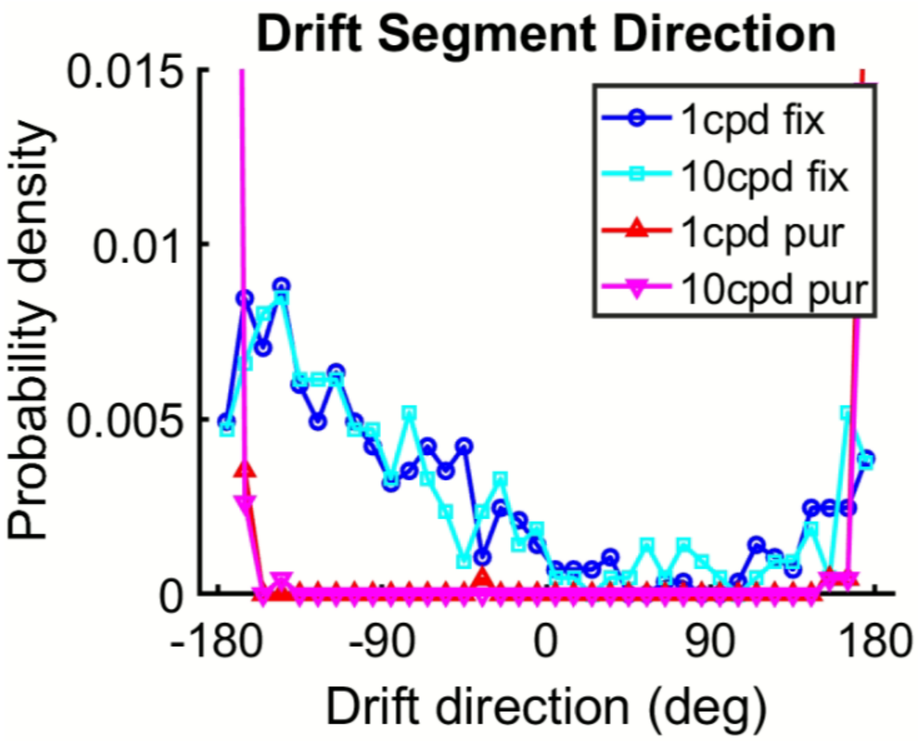
Segment Direction Distribution: No Noise | Contrast at 90%

- ➢ More towards left (±180°) in pursuit trails ($g_{10} < g_1 \ll 1$)

Bin



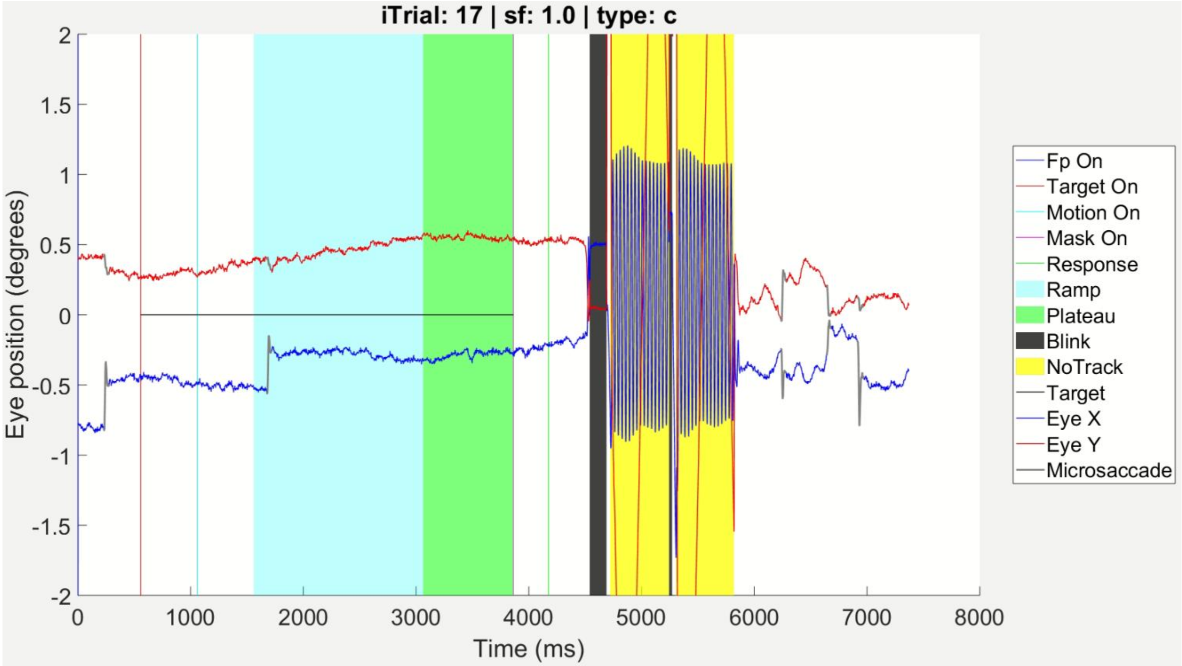
A081



❖ Supplementary

Example Trials from Bin

Fixation



Pursuit (Relative to Target)