

Visual Timing Sensitivity in a World Class Drum Corps:



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The Bluecoats!



https://en.wikipedia.org/wiki/Bluecoats_Drum_and_Bugle_Corps#/media/File:Bluecoats_large_logo.png

https://en.wikipedia.org/wiki/Bluecoats_Drum_and_Bugle_Corps#/media/File:TILTdrumbreak.jpg

Bluecoats Color Guard



Prediction: Color Guard superiority in visual TOJs.



https://en.wikipedia.org/wiki/Bluecoats_Drum_and_Bugle_Corps#/media/File:TILTdrumbreak.jpg

Prediction:
Musician superiority in visual TOJs.



https://en.wikipedia.org/wiki/Bluecoats_Drum_and_Bugle_Corps#/media/File:TILTdrumbreak.jpg

Prediction:

Musician superiority in visual TOJs.

- **In principle, years of time-sensitive AUDITORY musical training might transfer to VISUAL stimuli.**

- **Audition dominates vision in duration perception.**

Ortega, L., Guzman-Martinez, E., Grabowecky, M., & Suzuki, S. (2014)

- **Musical training generalizes across modalities.**

Aagten-Murphy, D., Cappagli, G., & Burr, D. (2014).

Cicchini, G. M., Arrighi, R., Cecchetti, L., Giusti, M., & Burr, D. C. (2012).

Research Question:

Do VISUALLY defined TOJs
improve more from
VISUAL (color guard) training
or from
AUDITORY (musical) training?

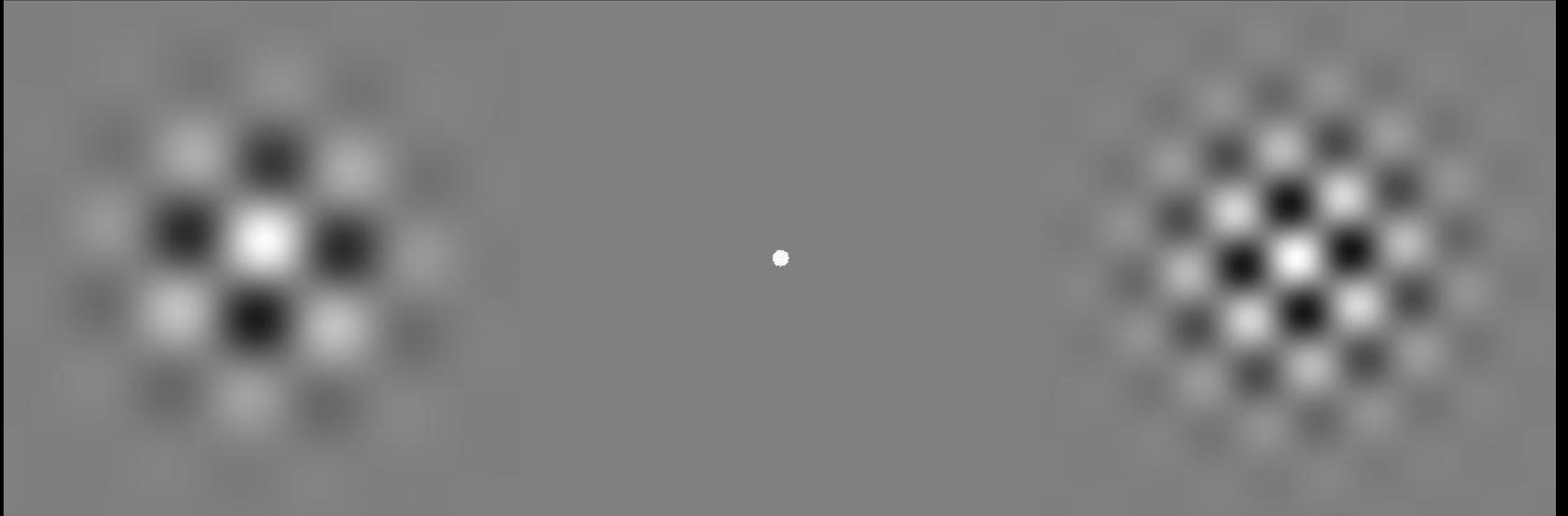
Methodological Details

- 121 Members of the 2017 Bluecoats
 - Percussion: N = 25
 - Brass: N = 67
 - Color Guard: N = 29
- 121 Members * 560 Trials = 67,760 Trials

Methodological Details

- Quasi-Experimental Design
- Independent Variables
 - Group (Percussion vs Brass vs Color Guard) between-participants (pre-existing)
 - Motion Type (Radial vs Rotational) within-participants
 - Initial Direction (Same vs Opposite) within-participants
 - Asynchrony (-200, -133, -67, 0, 67, 133, 200 msec) within-participants
- Dependent Variable
 - Precision on Temporal Order Judgment (TOJ) Task...

Temporal Order Judgement (TOJ) Task



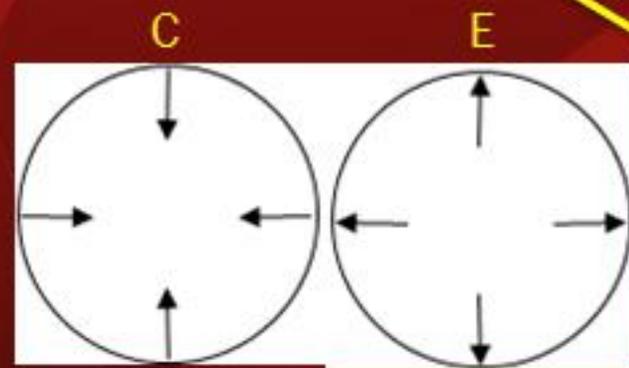
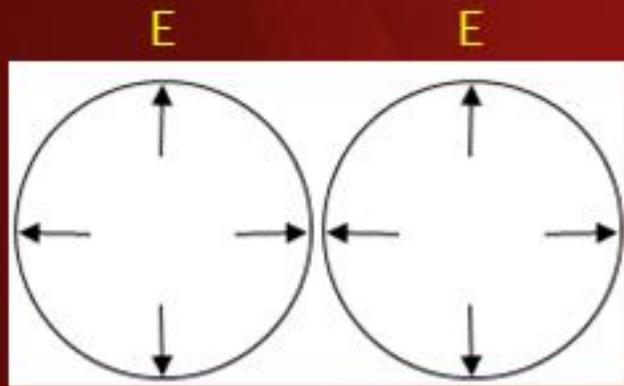
Which side changed direction first?

← Left

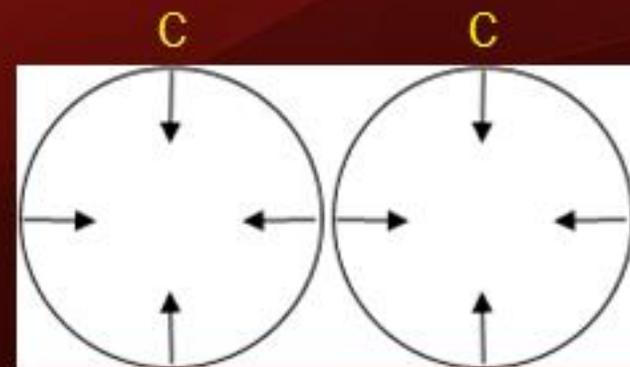
or

Right →

Radial Same

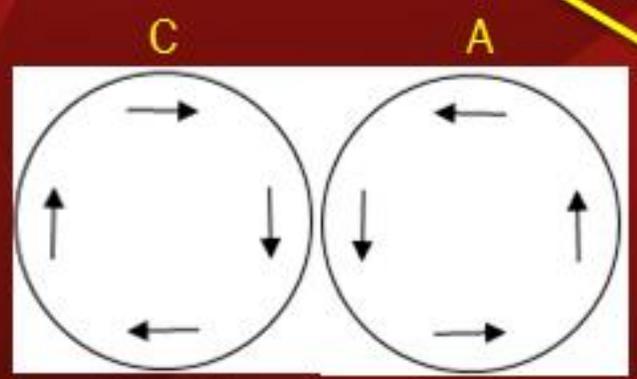
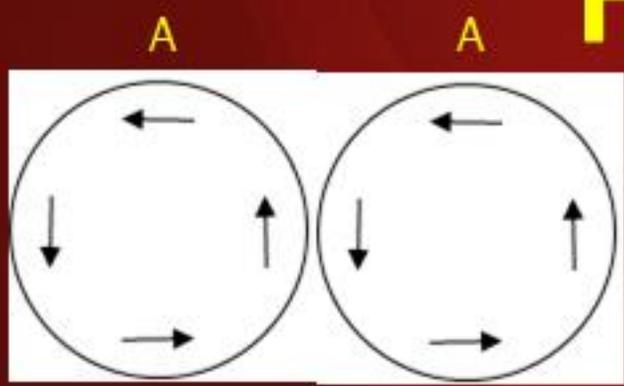


Left Side
Changes
1st

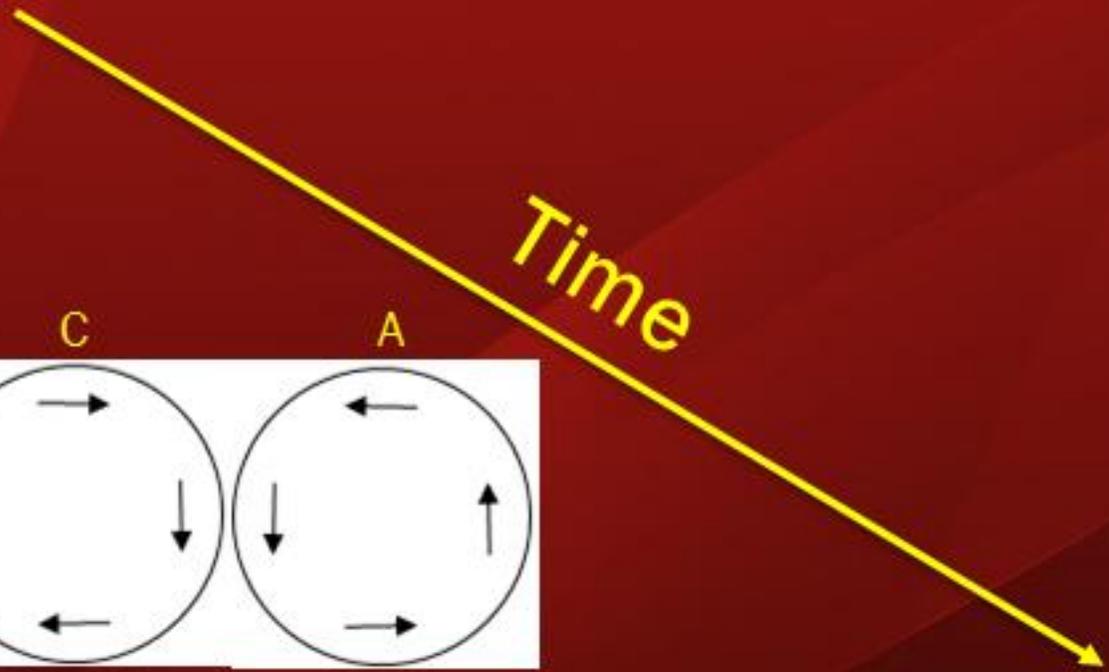
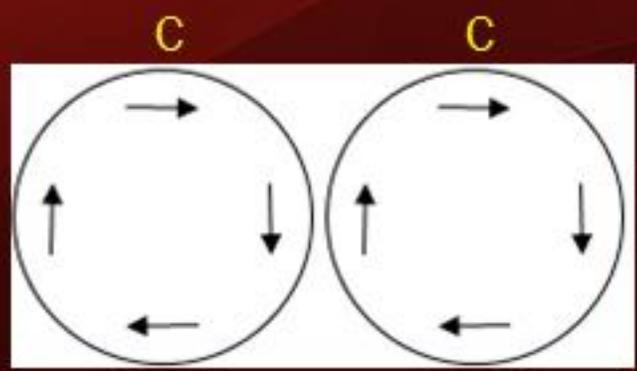


Time

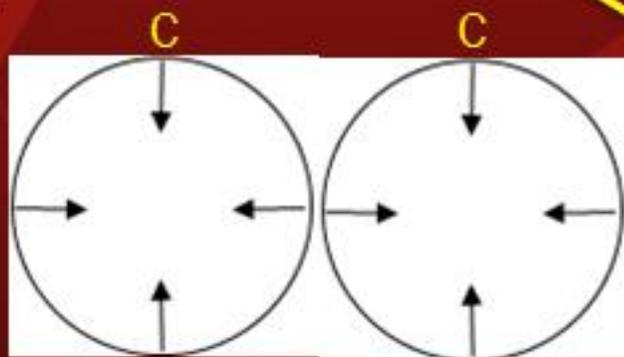
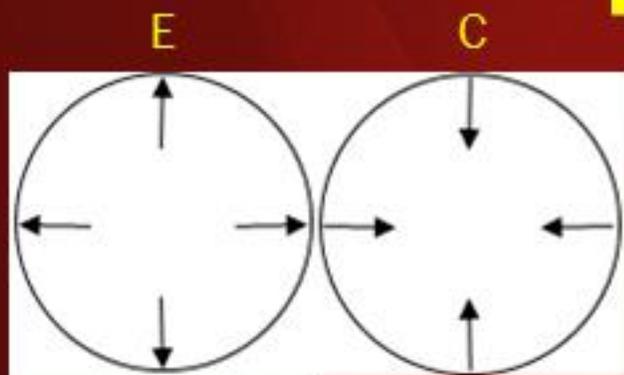
Rotational Same



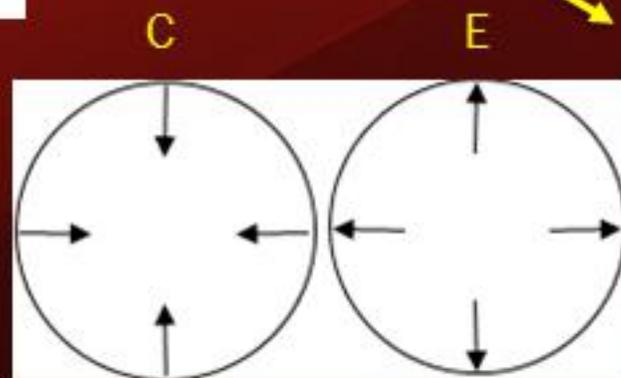
Left Side
Changes
1st



Radial Opposite

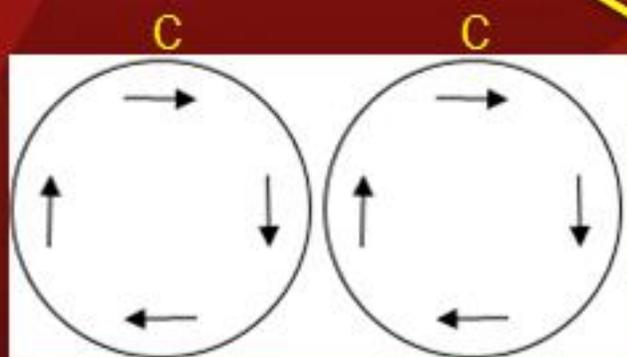
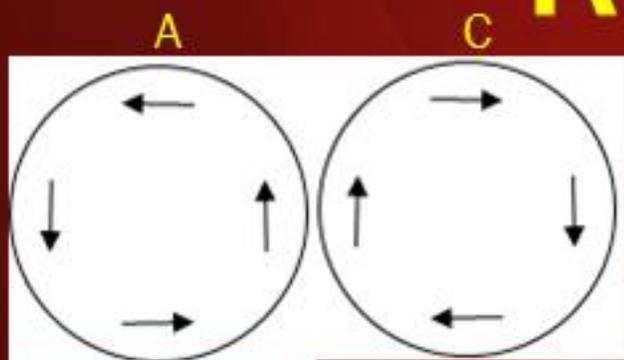


Left Side
Changes
1st

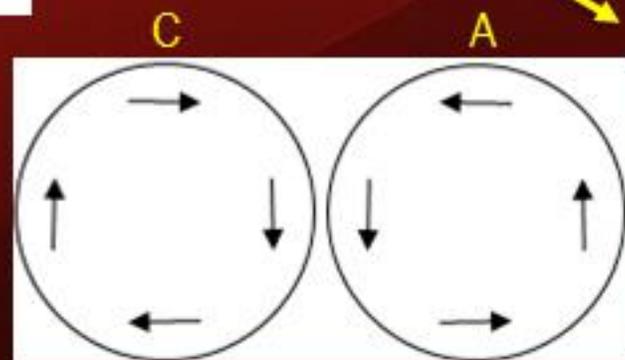


Time

Rotational Opposite



Left Side
Changes
1st

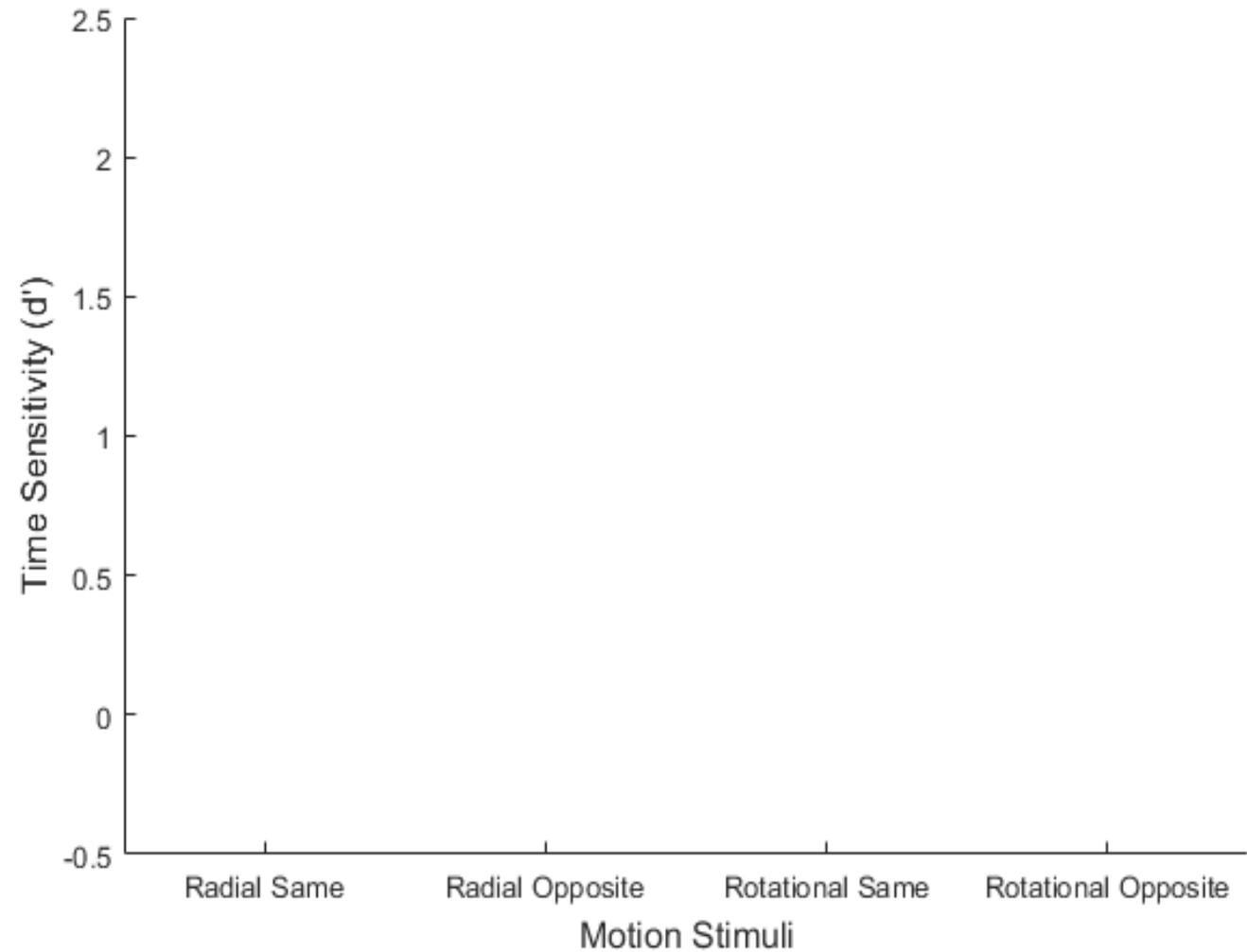


Time

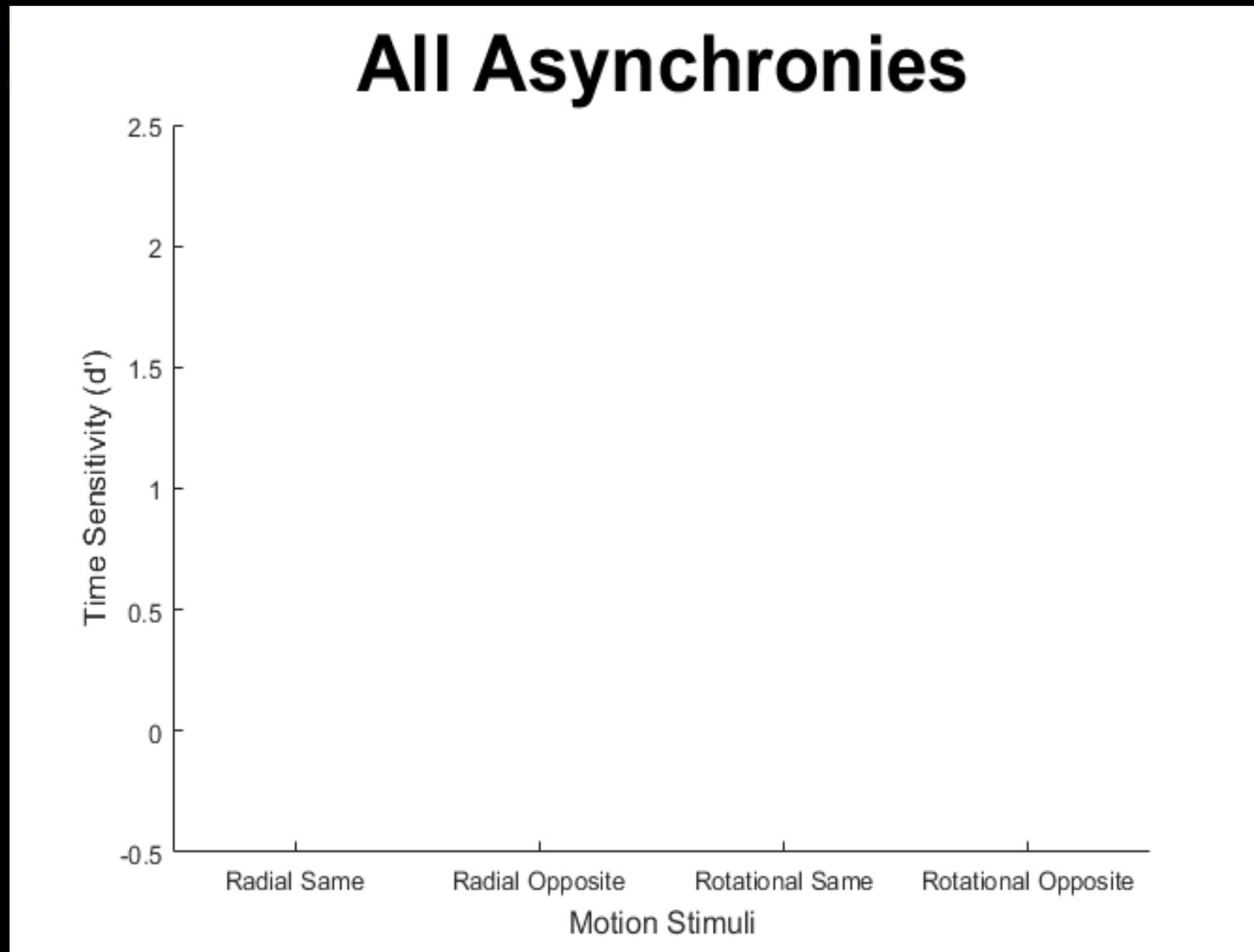
Psychophysical Results

Group Differences in Time Sensitivity (d')

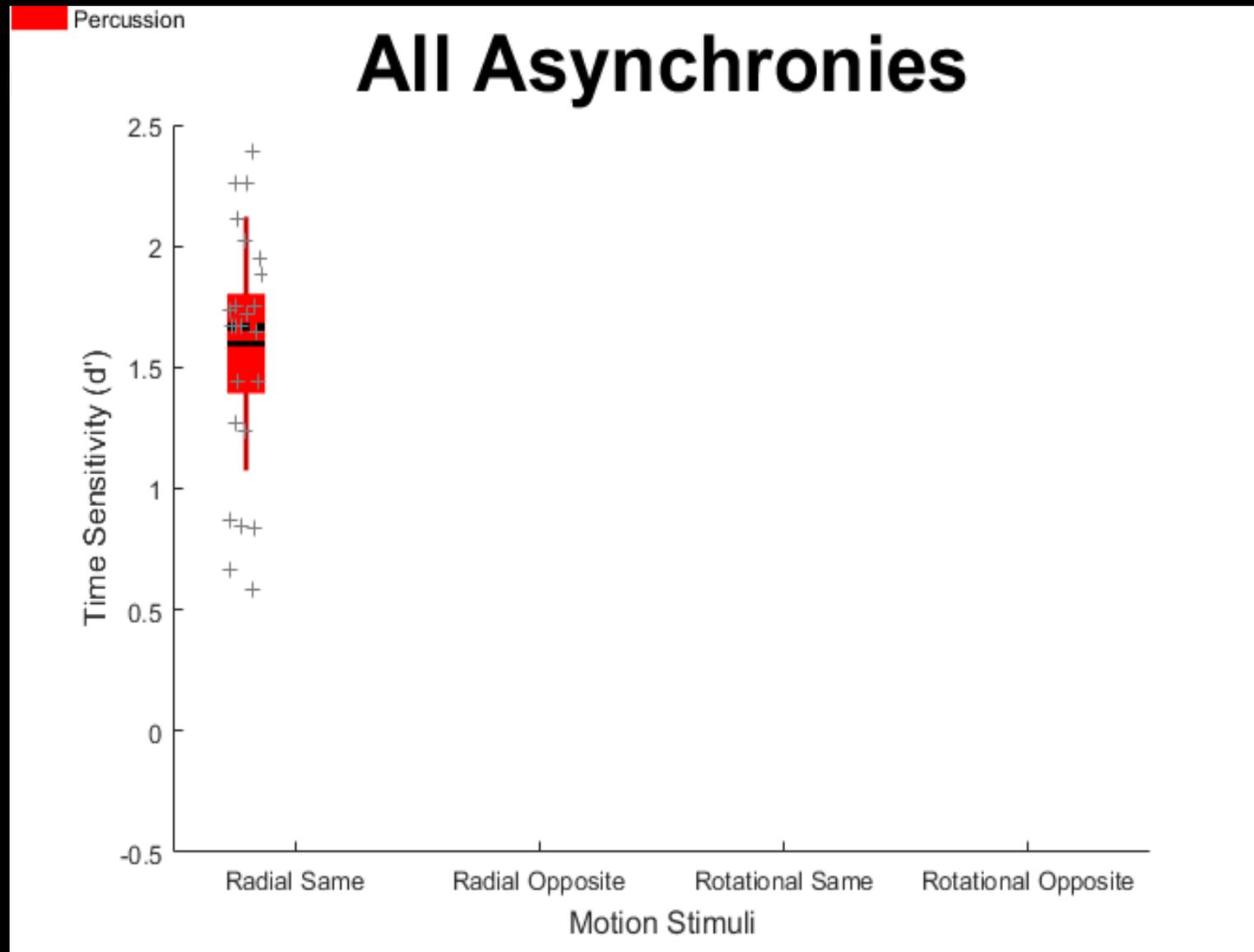
Group Differences in Time Sensitivity (d')



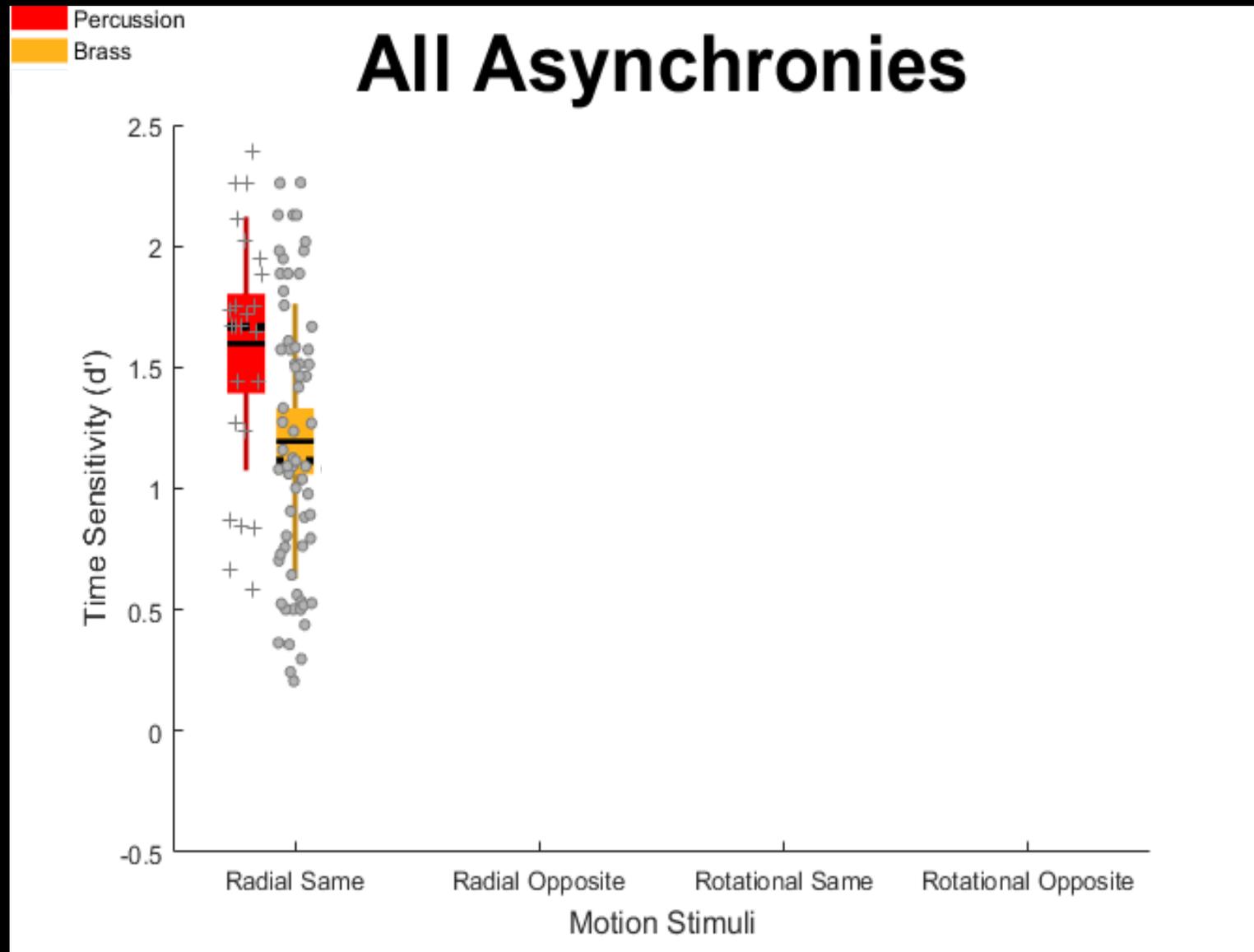
Group Differences in Time Sensitivity (d')



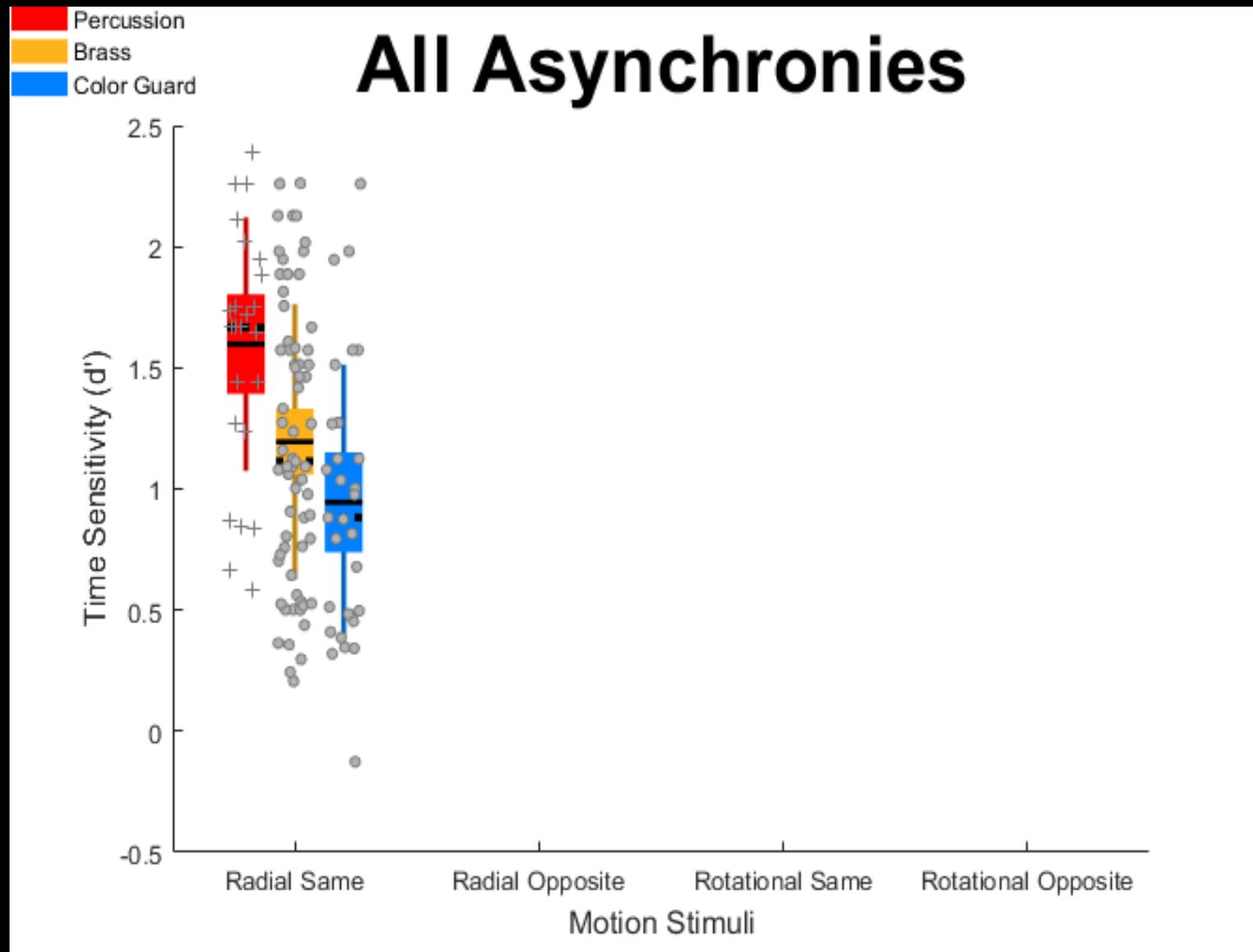
Group Differences in Time Sensitivity (d')



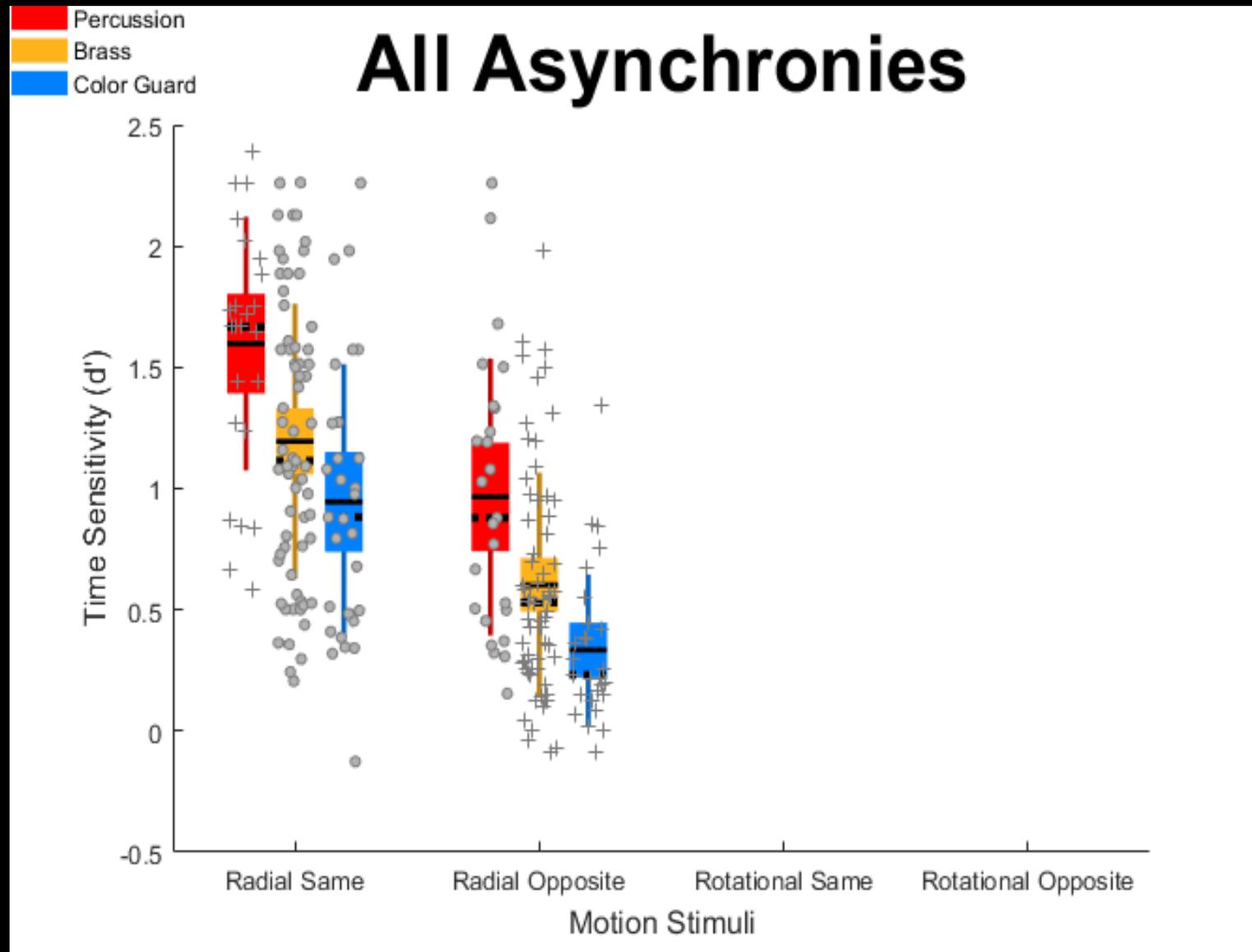
Group Differences in Time Sensitivity (d')



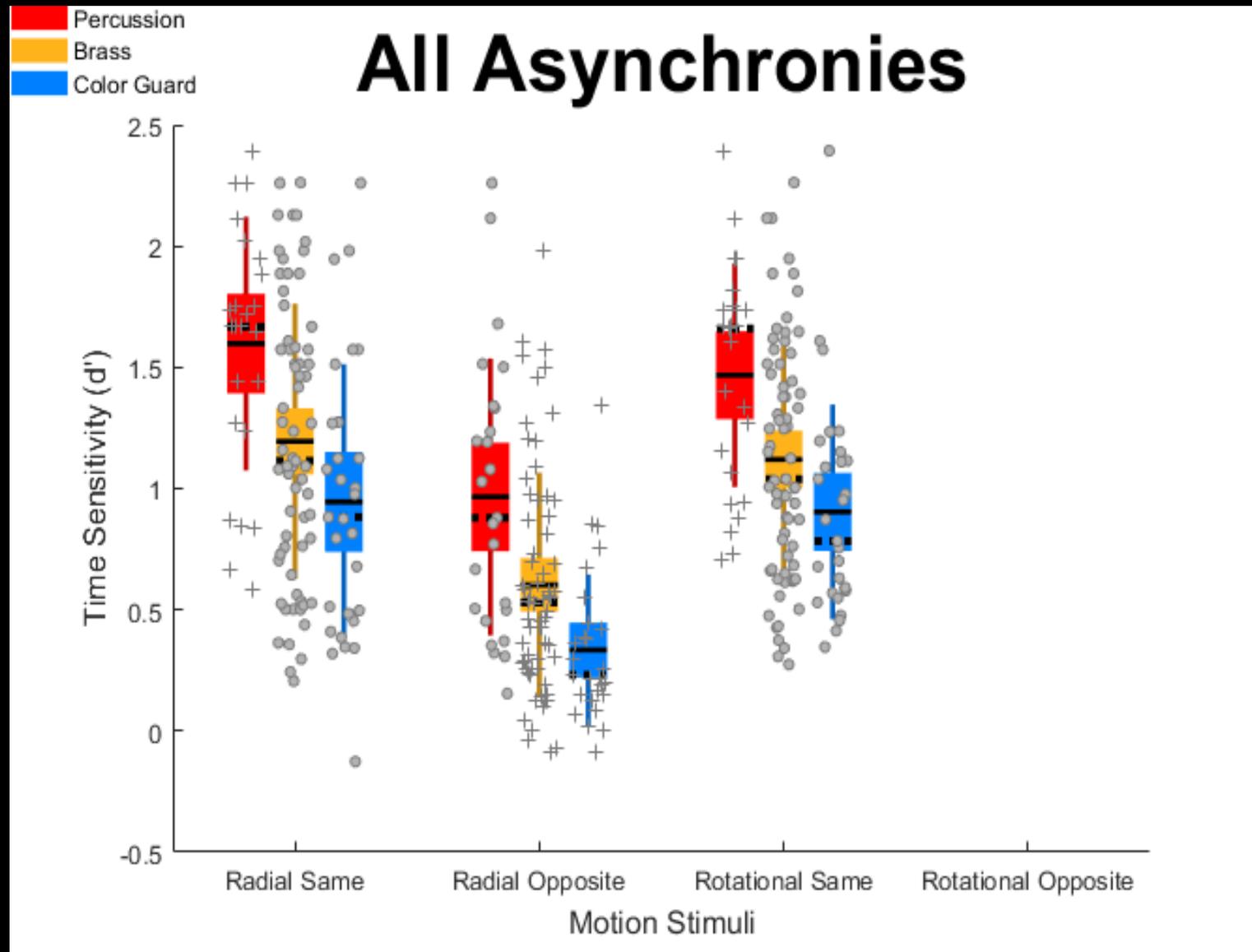
Group Differences in Time Sensitivity (d')



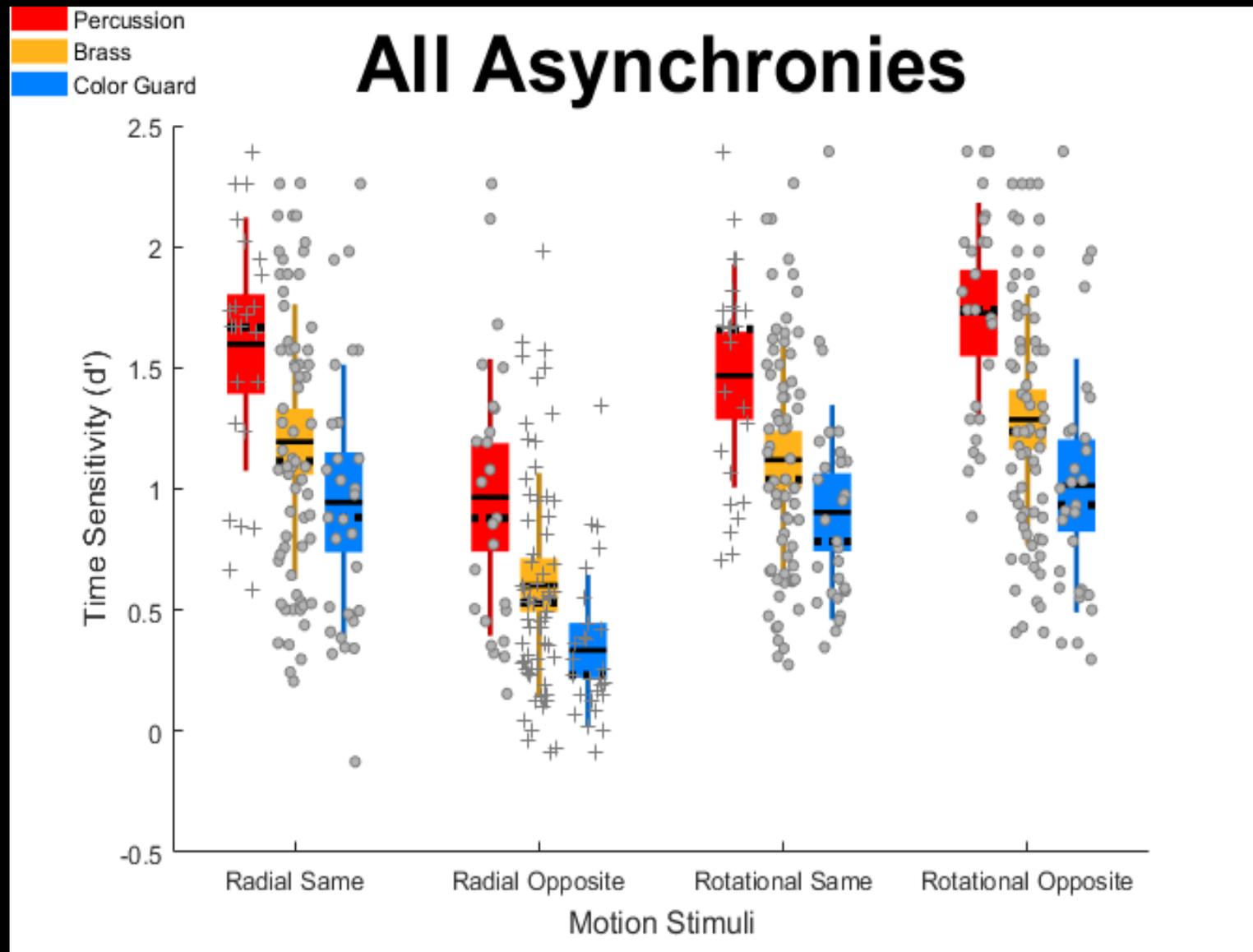
Group Differences in Time Sensitivity (d')



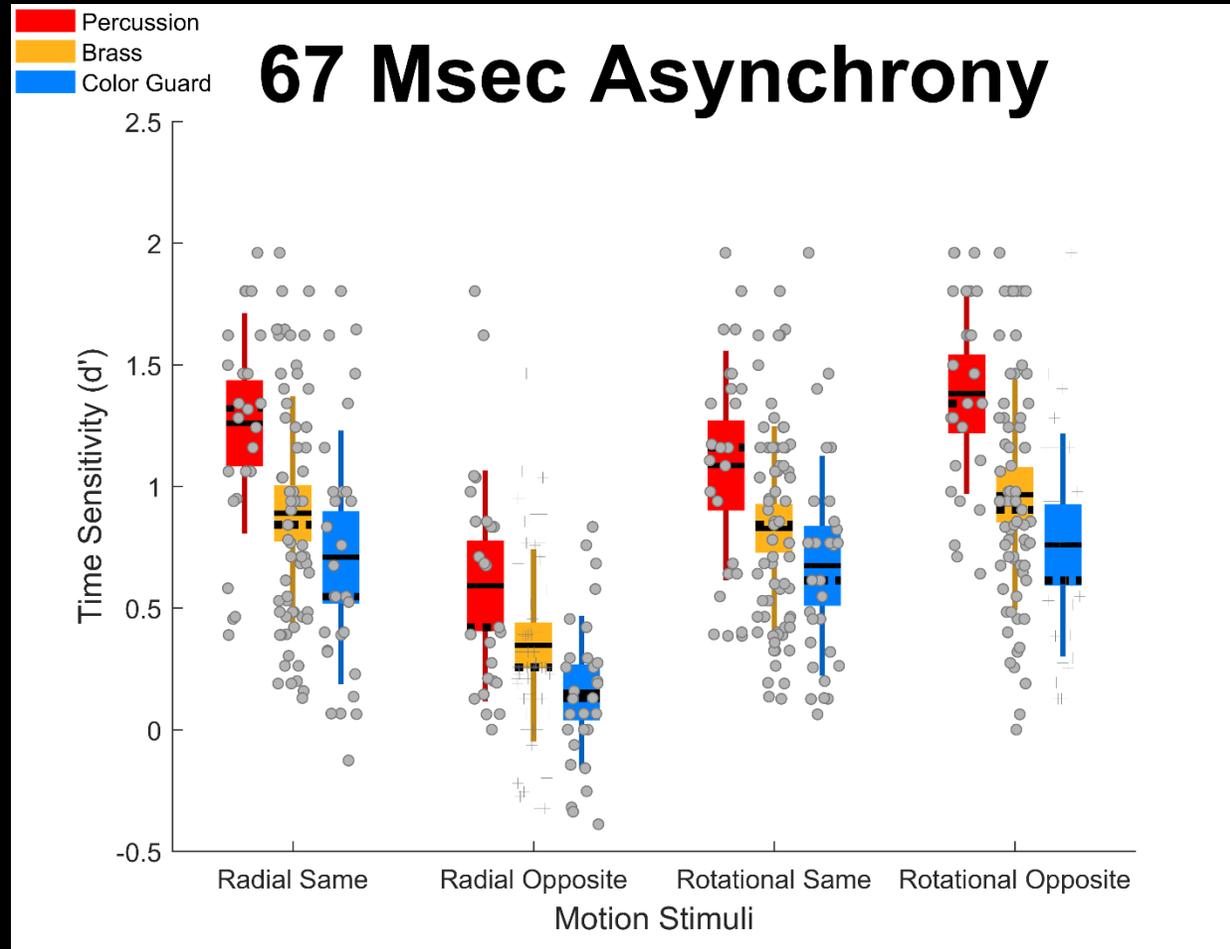
Group Differences in Time Sensitivity (d')



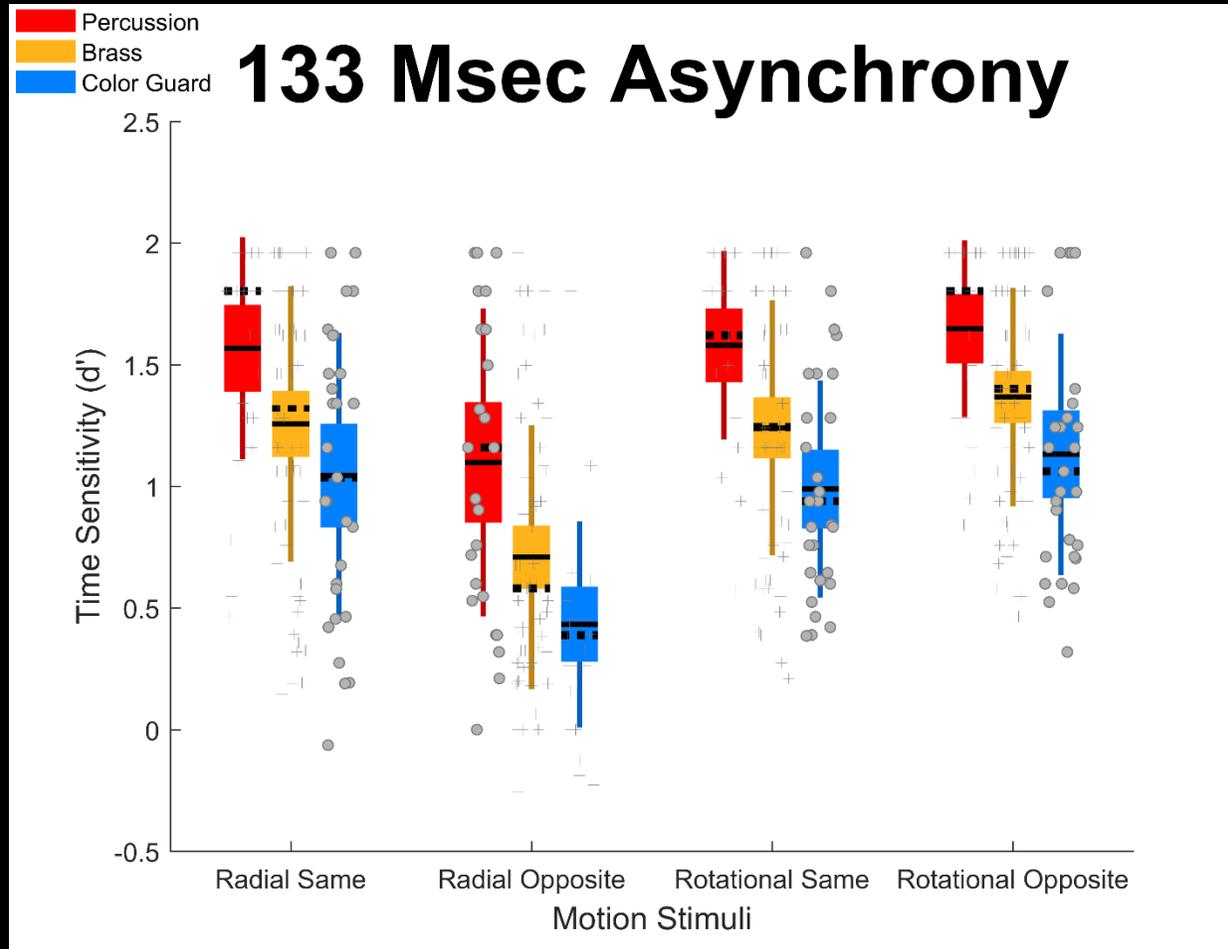
Group Differences in Time Sensitivity (d')



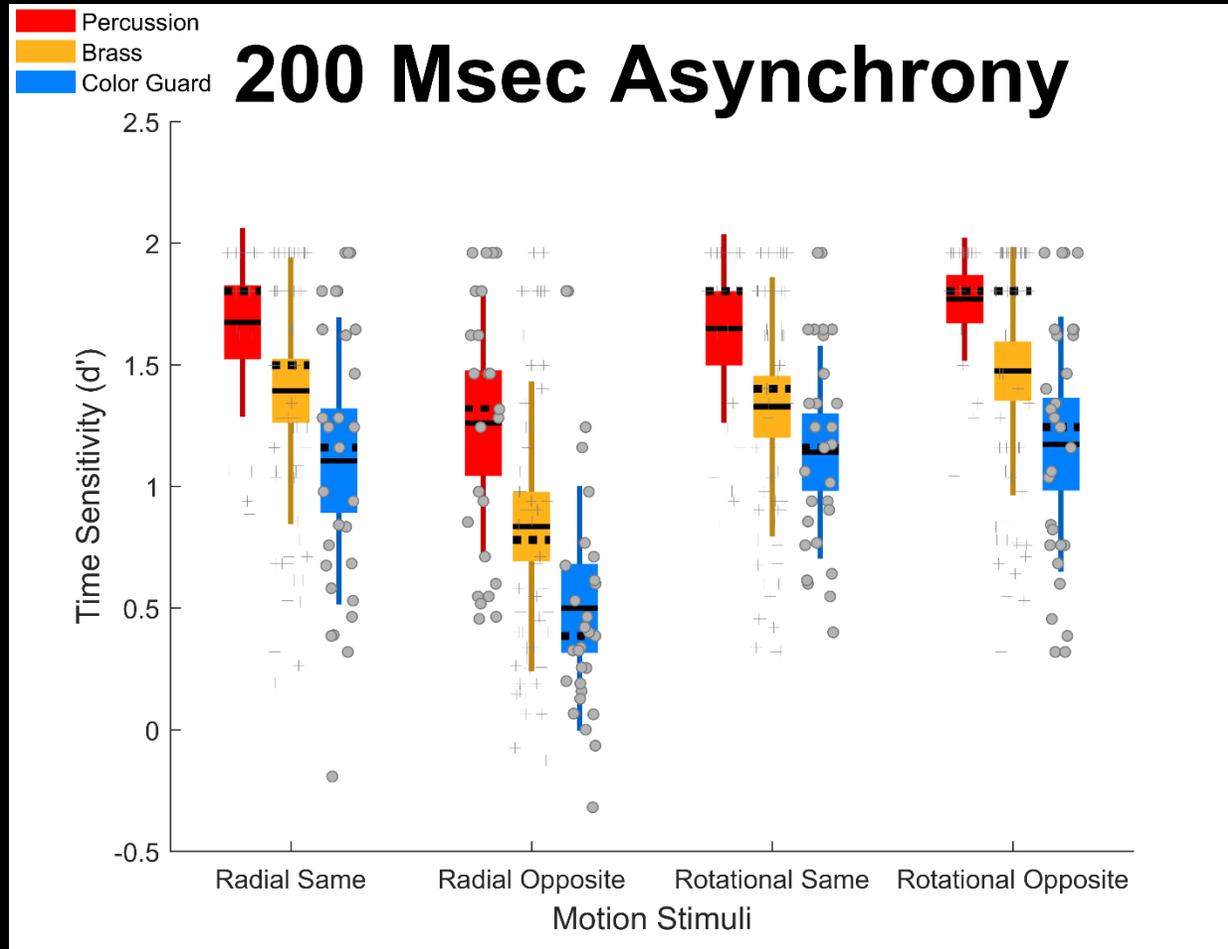
Group Differences in Time Sensitivity (d')



Group Differences in Time Sensitivity (d')



Group Differences in Time Sensitivity (d')



Group Differences in Time Sensitivity (d')

Motion Condition	Group Comparison	Median Difference (d')	Monte Carlo P-Value
Radial Same			
	Percussion vs Brass	0.5530	0.0031
	Brass vs Color Guard	0.2323	0.0447
	Percussion vs Color Guard	0.7853	0.0006

Group Differences in Time Sensitivity (d')

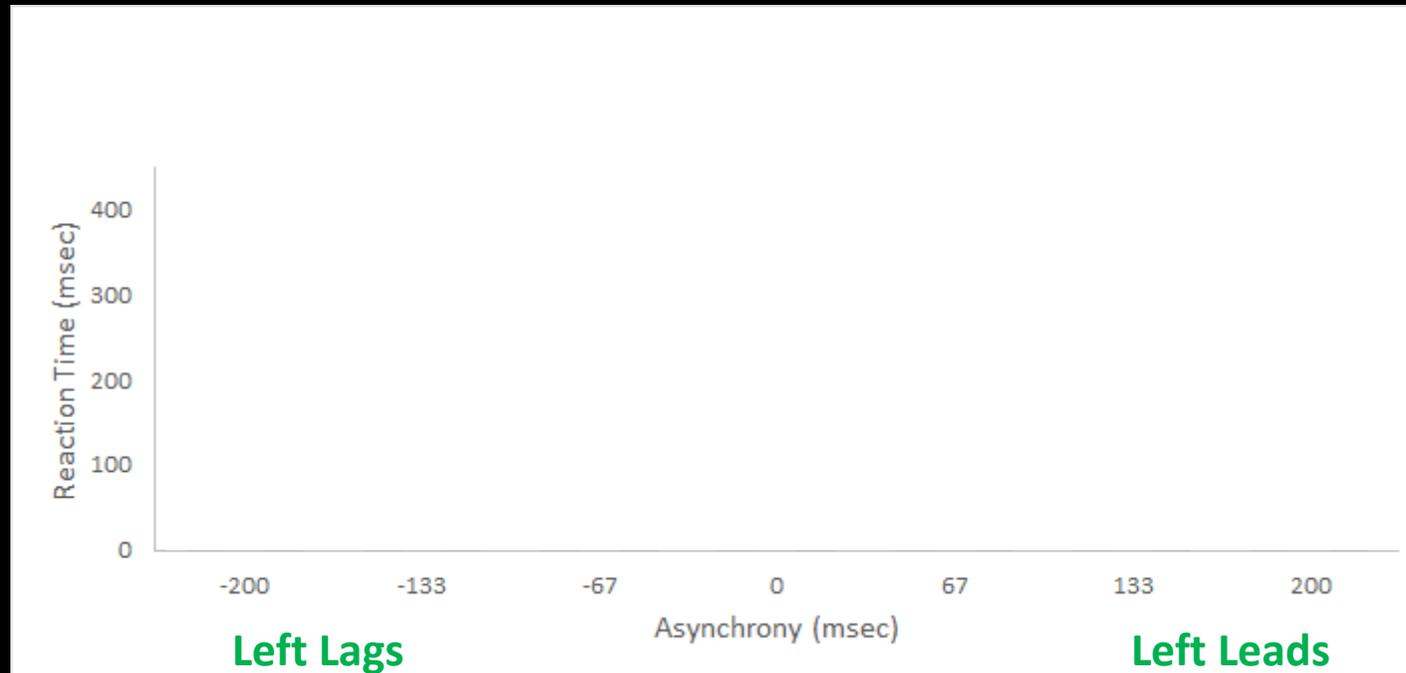
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Radial Same	Percussion vs Brass	0.5530	0.0031
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	Percussion vs Color Guard	0.7853	0.0006

Group Differences in Time Sensitivity (d')

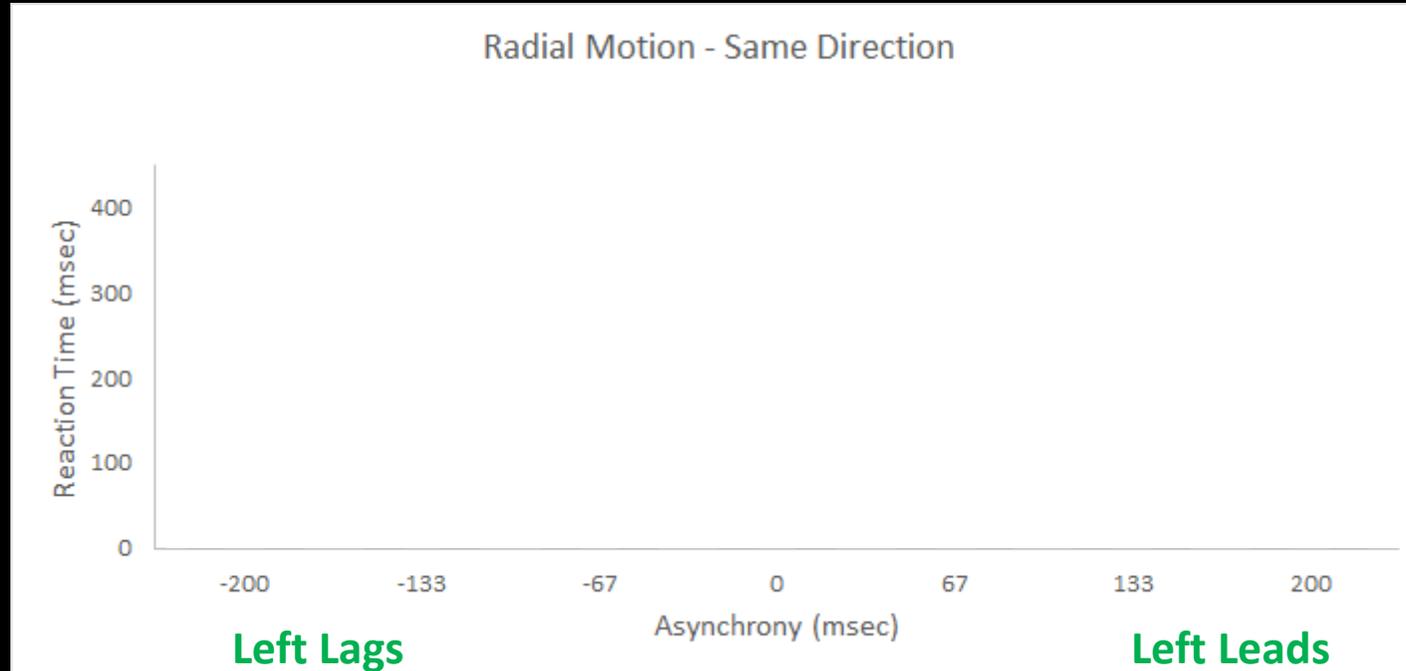
Motion Condition	Group Comparison	Median Difference (d')	Monte Carlo P-Value
Radial Same	Percussion vs Brass	0.5530	0.0031
	Brass vs Color Guard	0.2323	0.0447
	Percussion vs Color Guard	0.7853	0.0006
Radial Opposite	Percussion vs Brass	0.3494	0.0188
	Brass vs Color Guard	0.2980	0.0002
	Percussion vs Color Guard	0.6474	<0.0001
Rotational Same	Percussion vs Brass	0.6208	0.0001
	Brass vs Color Guard	0.2556	0.0397
	Percussion vs Color Guard	0.8764	<0.0001
Rotational Opposite	Percussion vs Brass	0.5027	0.0033
	Brass vs Color Guard	0.3035	0.0216
	Percussion vs Color Guard	0.8062	<0.0001

Group Differences in Reaction Time

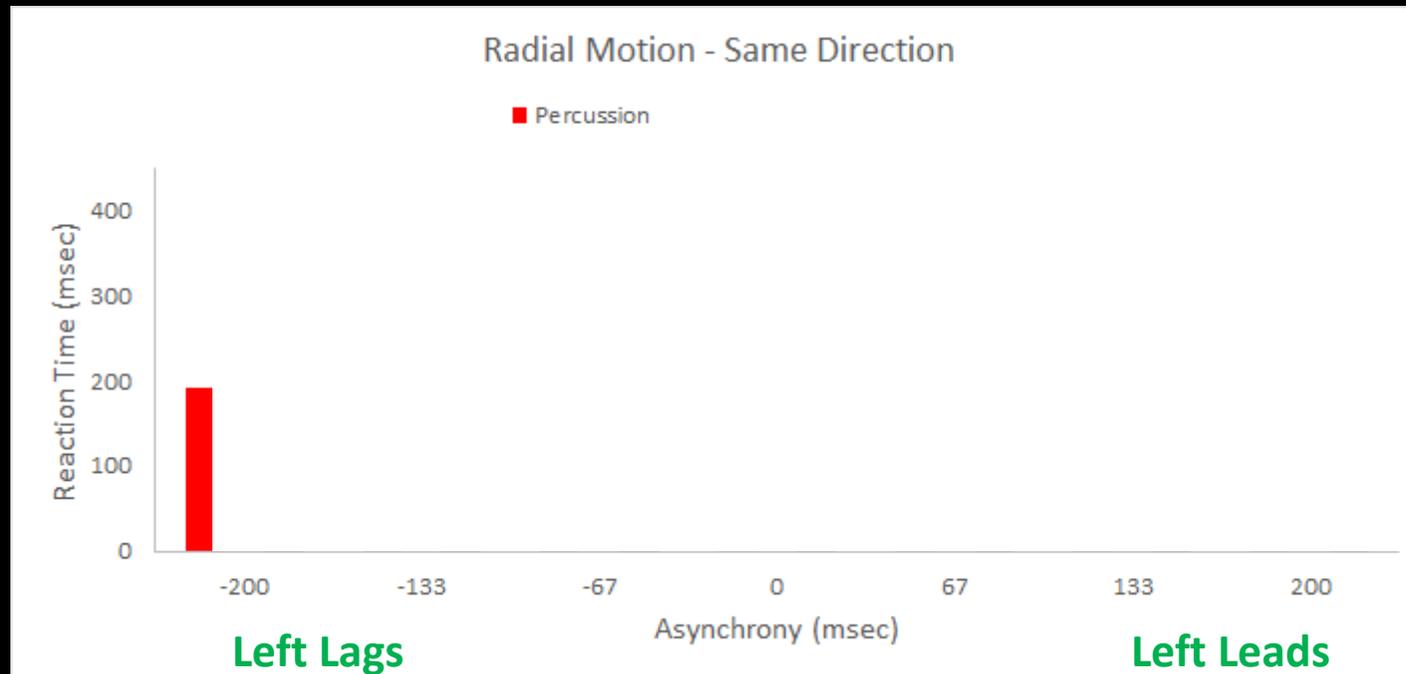
Group Differences in Reaction Time



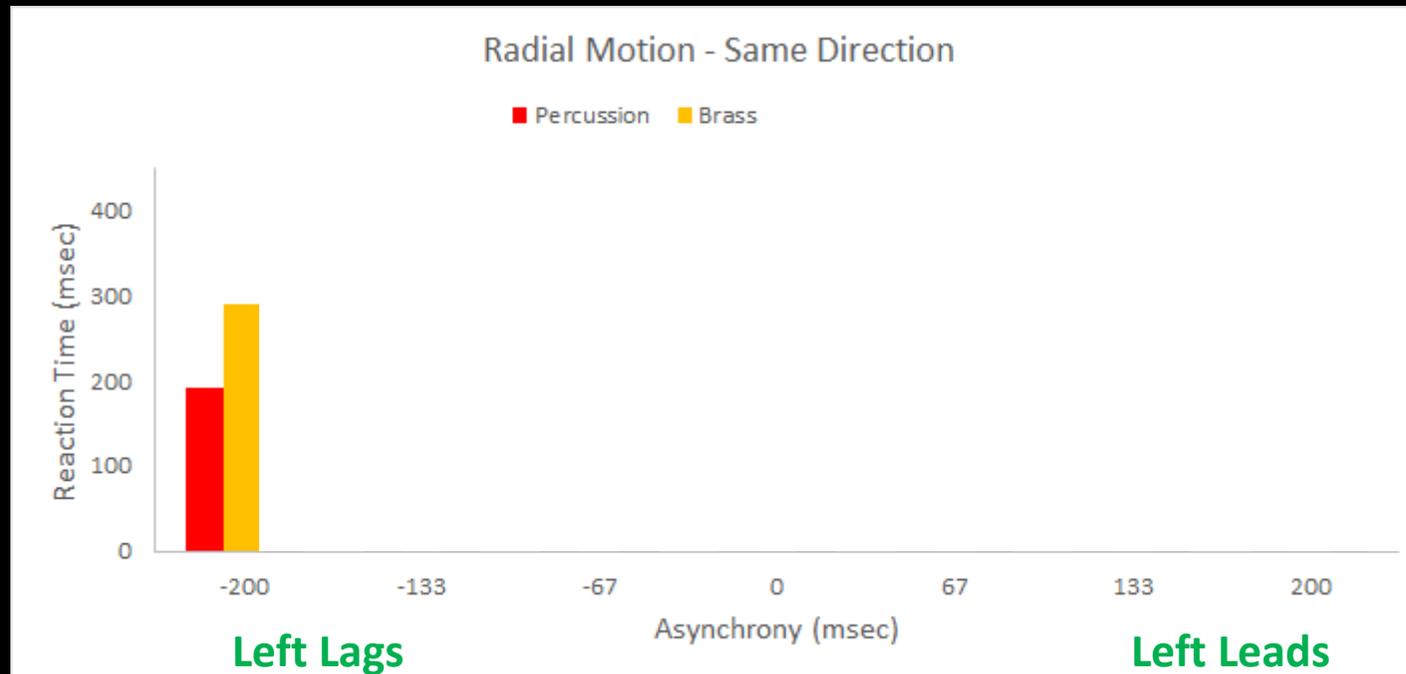
Group Differences in Reaction Time



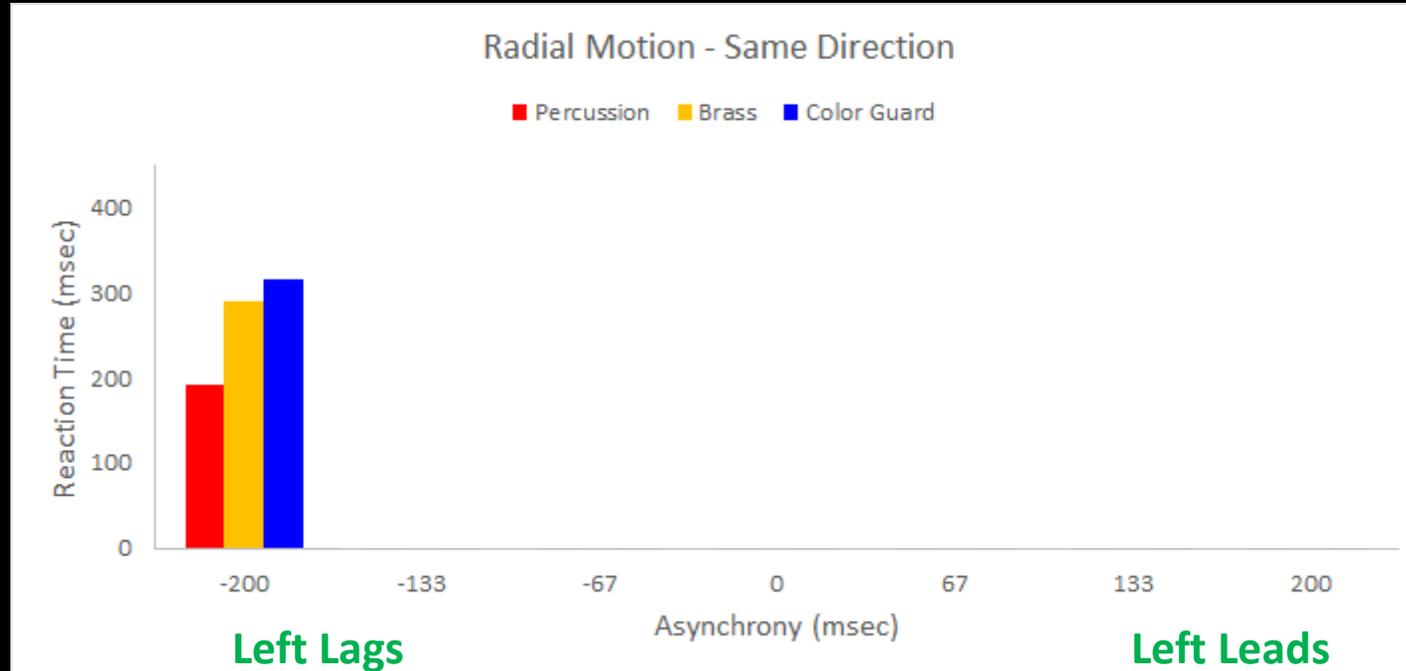
Group Differences in Reaction Time



Group Differences in Reaction Time



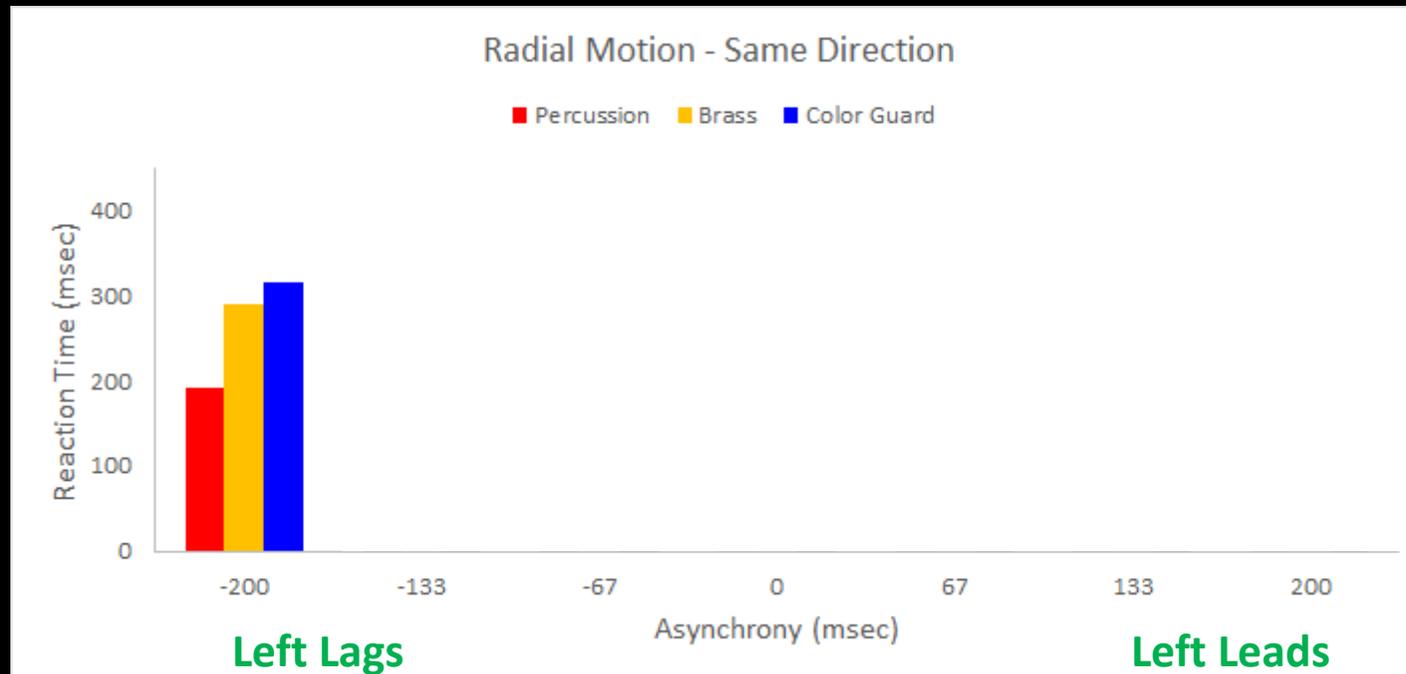
Group Differences in Reaction Time



Group Differences in Reaction Time

6 Permutations

*P B C



Group Differences in Reaction Time

6 Permutations

$$p = 1 / 6^1$$

*P B C

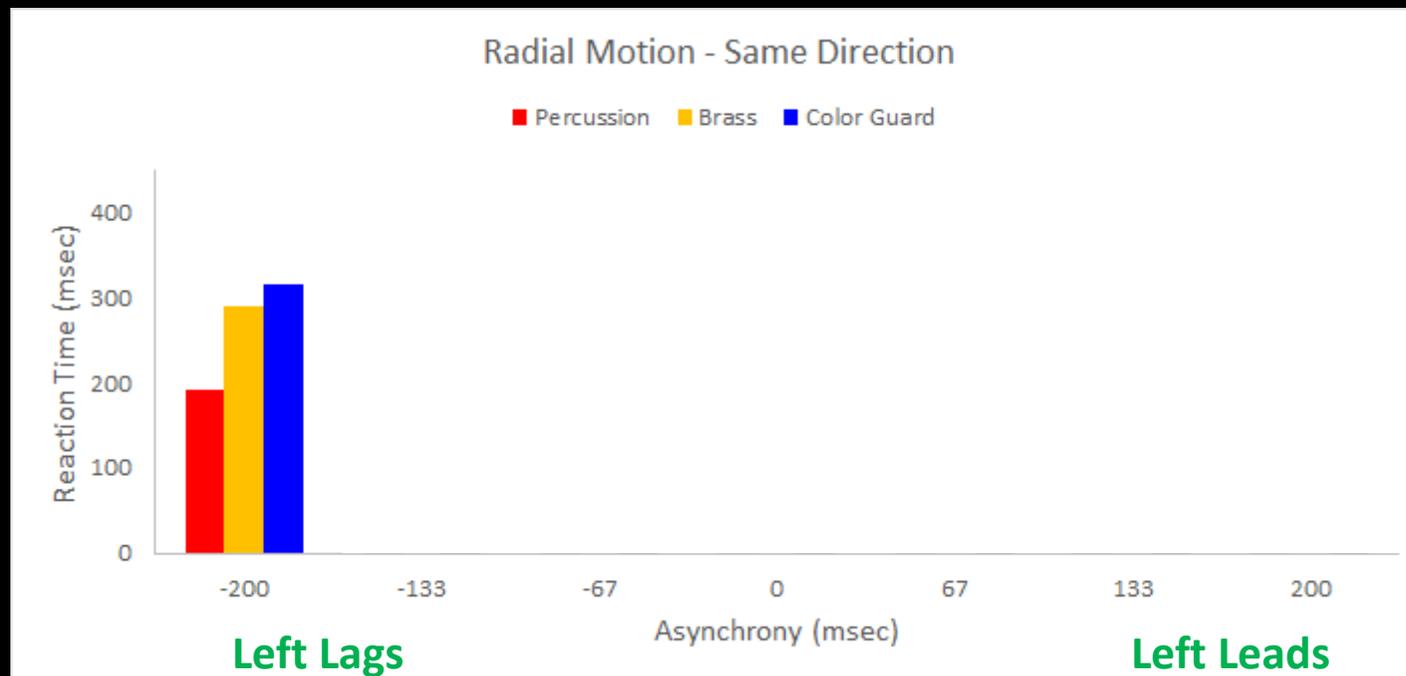
P C B

B C P

B P C

C P B

C B P



Group Differences in Reaction Time

6 Permutations

$$p = 1 / 6^2$$

* P B C

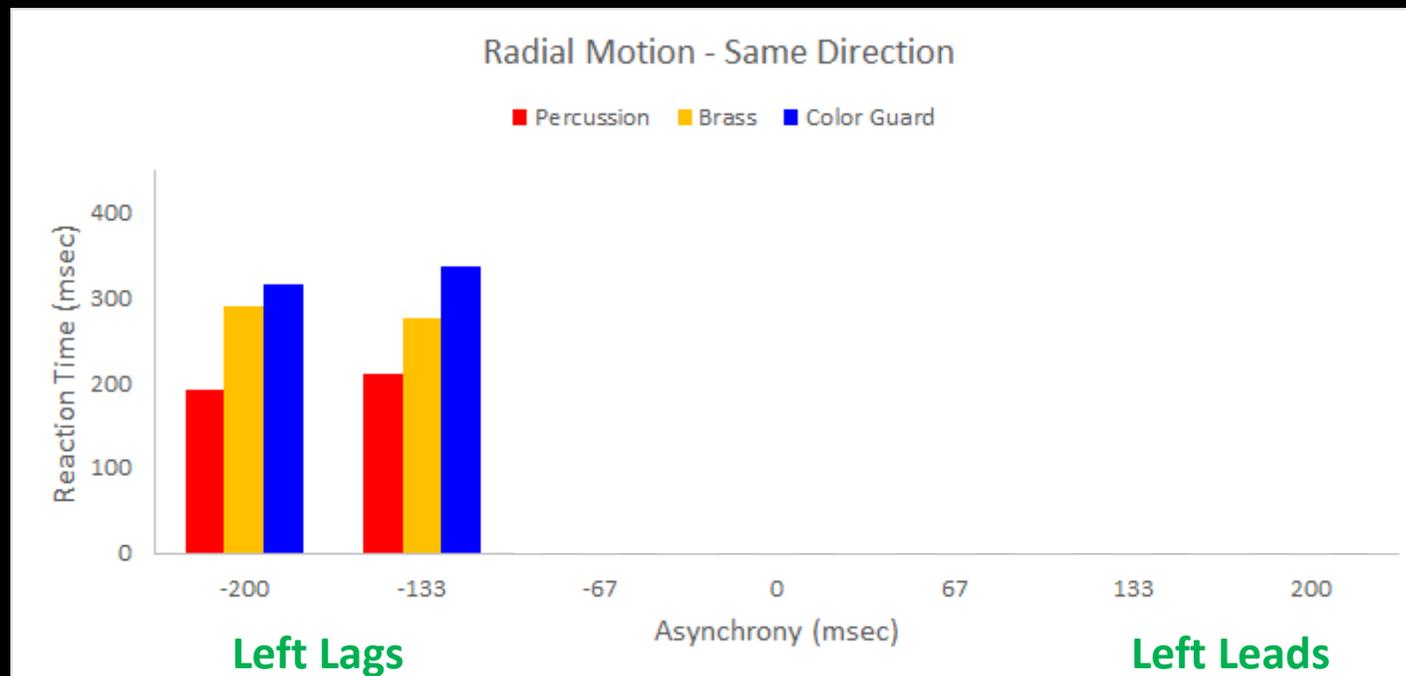
P C B

B C P

B P C

C P B

C B P



Group Differences in Reaction Time

6 Permutations

$$p = 1 / 6^3$$

* P B C

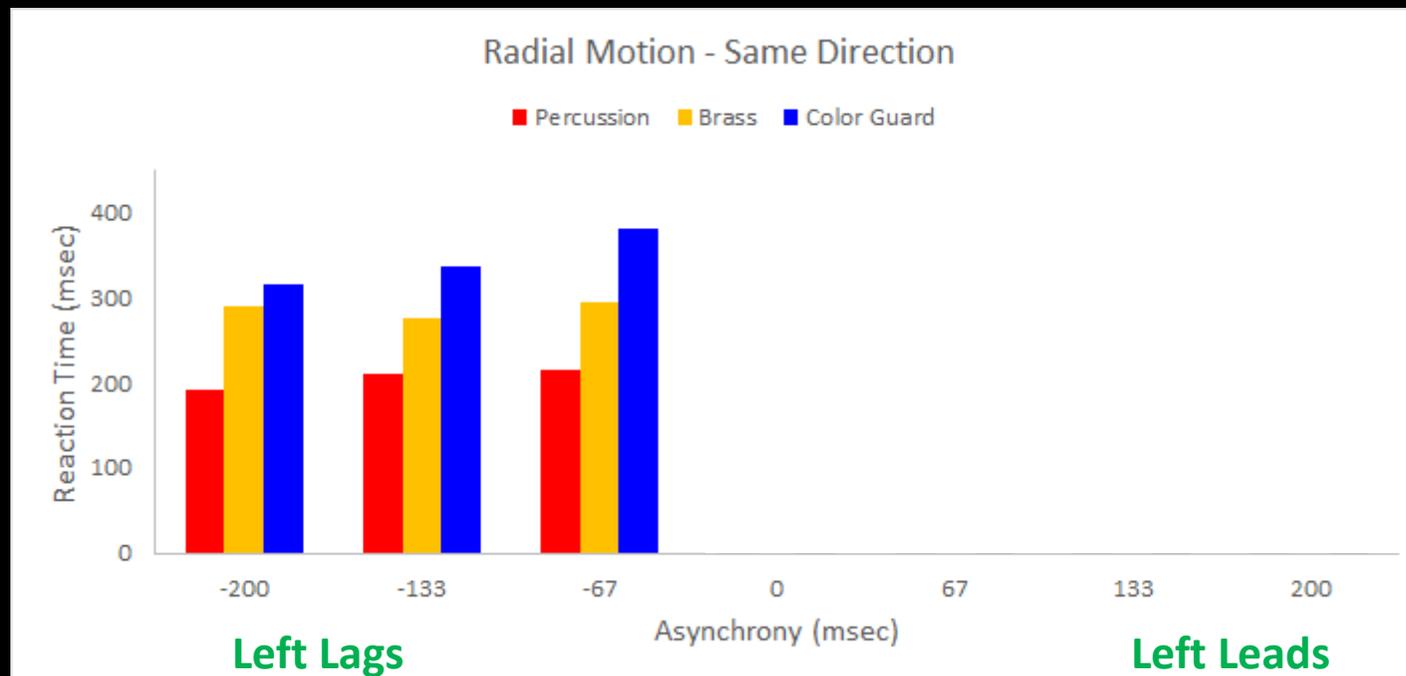
P C B

B C P

B P C

C P B

C B P



Group Differences in Reaction Time

6 Permutations

$$p = 1 / 6^4$$

*P B C

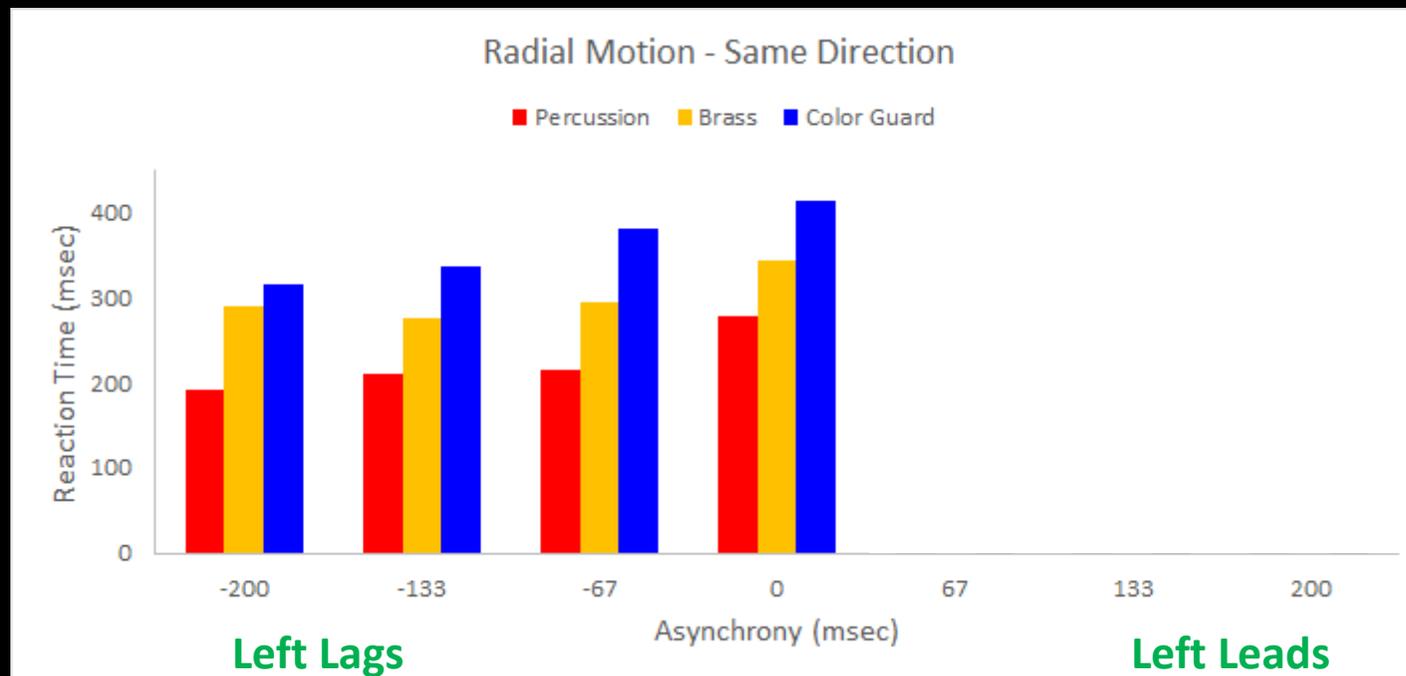
P C B

B C P

B P C

C P B

C B P



Group Differences in Reaction Time

6 Permutations

$$p = 1 / 6^5$$

*P B C

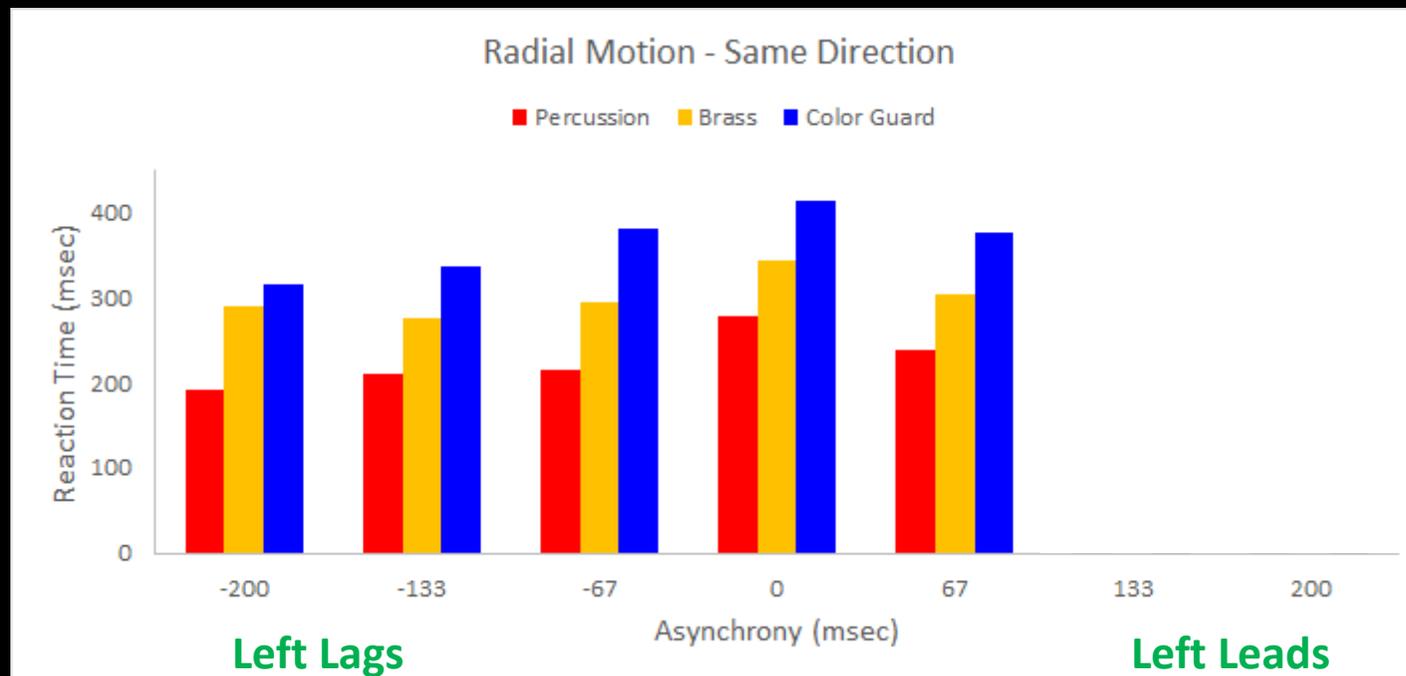
P C B

B C P

B P C

C P B

C B P



Group Differences in Reaction Time

6 Permutations

$$p = 1 / 6^6$$

* P B C

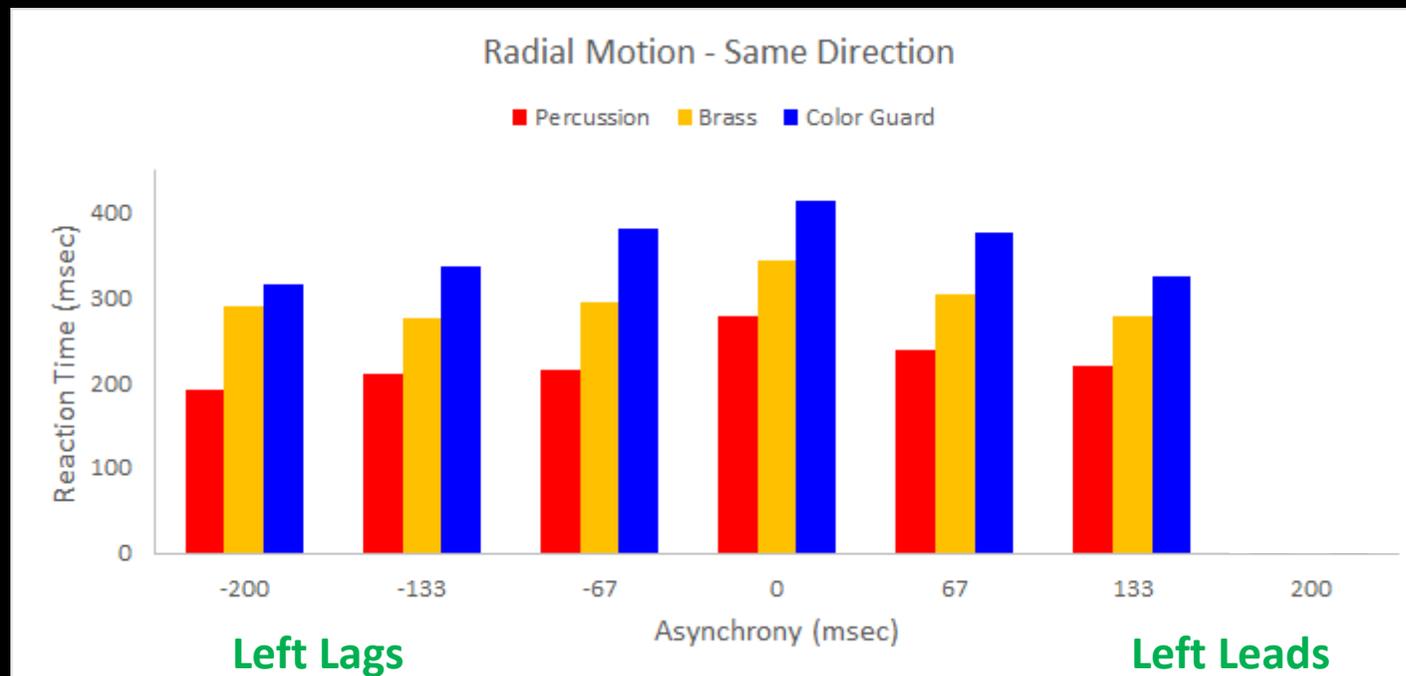
P C B

B C P

B P C

C P B

C B P



Group Differences in Reaction Time

6 Permutations

$$p = 1 / 6^7$$

*P B C

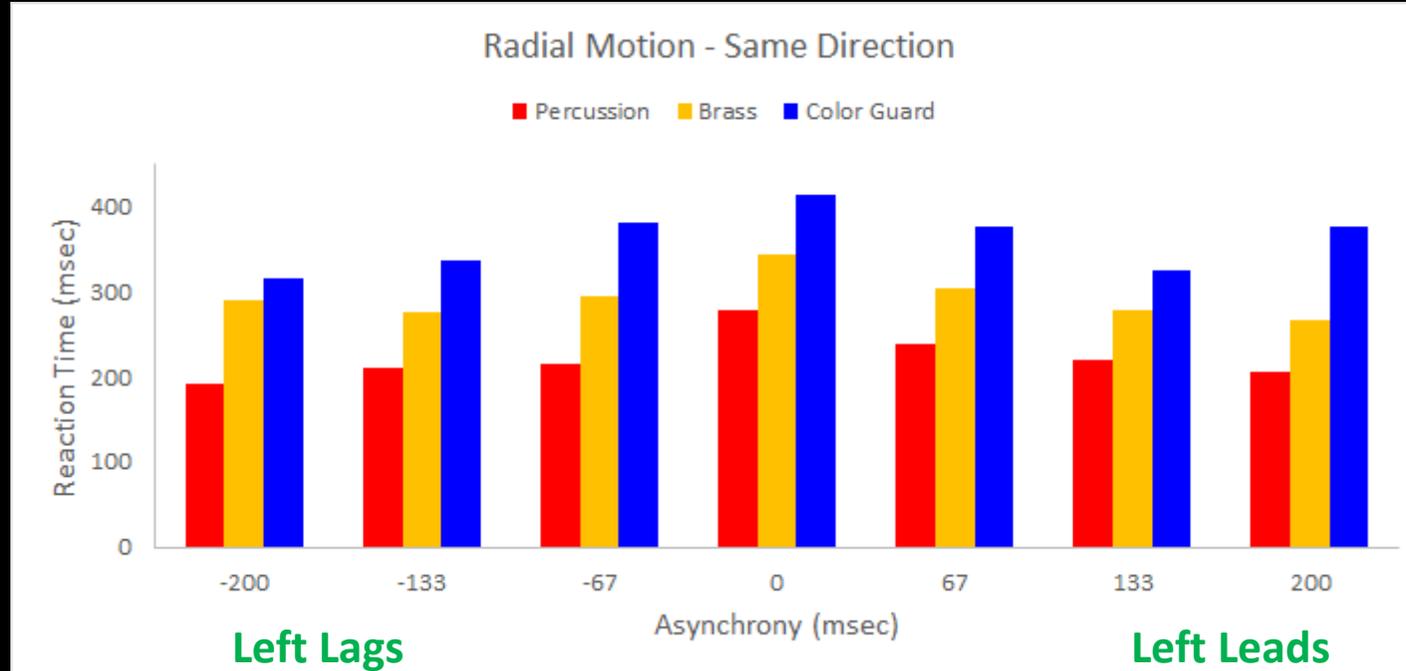
P C B

B C P

B P C

C P B

C B P



$$p = 0.00000357224$$

Group Differences in Reaction Time

6 Permutations

$$p = 1 / 6^7$$

*P B C

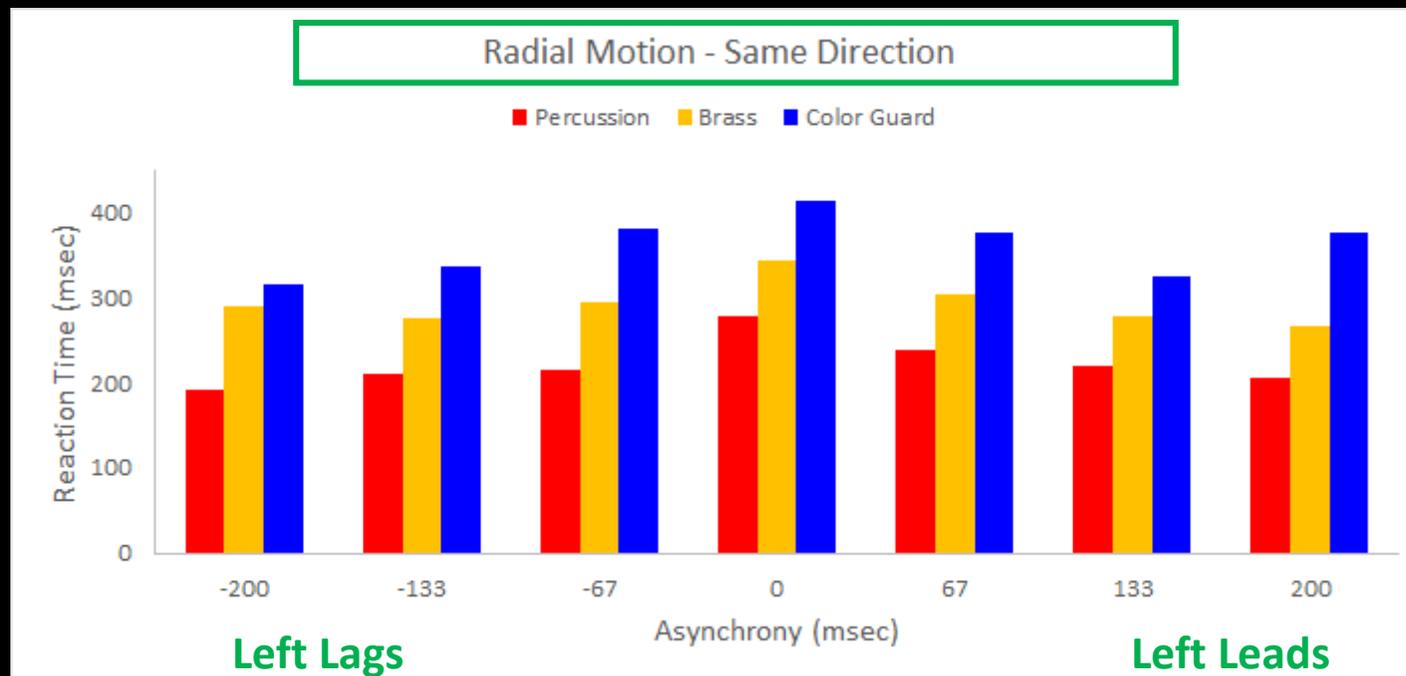
P C B

B C P

B P C

C P B

C B P



$$p = 0.00000357224$$

Group Differences in Reaction Time

6 Permutations

$$p = 1 / 6^7$$

* P B C

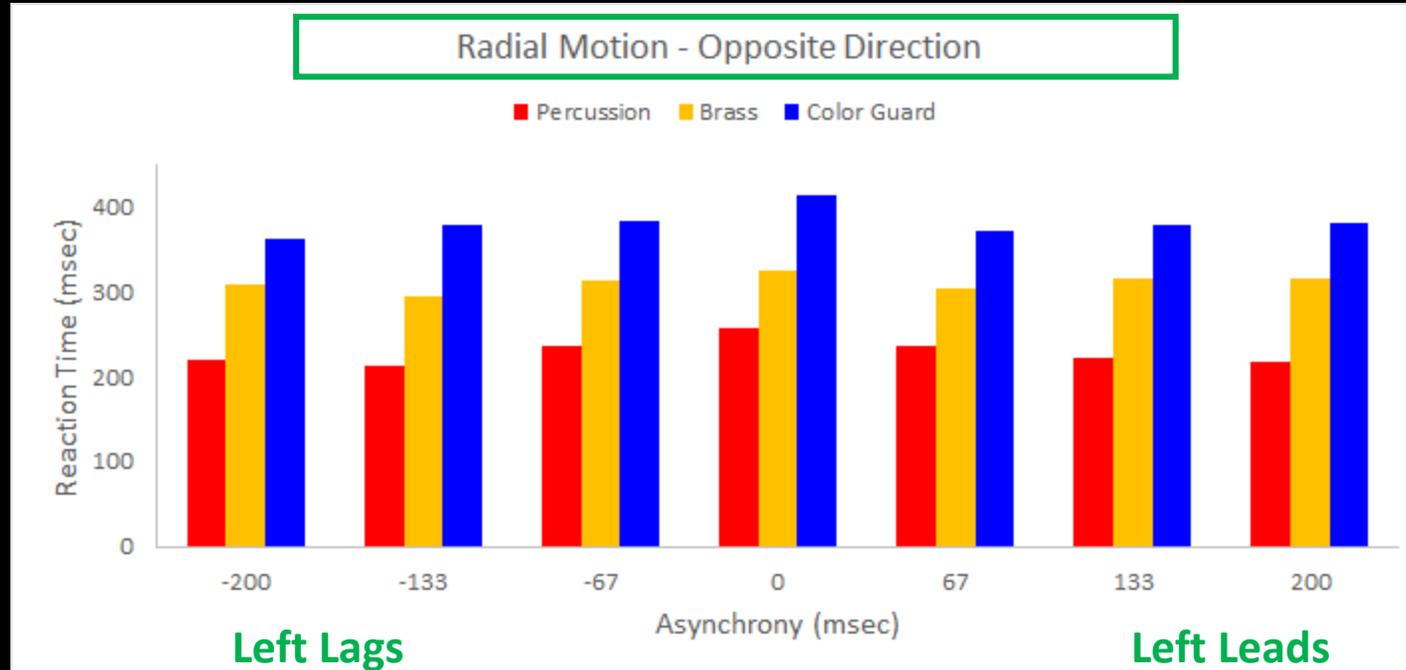
P C B

B C P

B P C

C P B

C B P



$$p = 0.00000357224$$

Group Differences in Reaction Time

6 Permutations

$$p = 1 / 6^7$$

*P B C

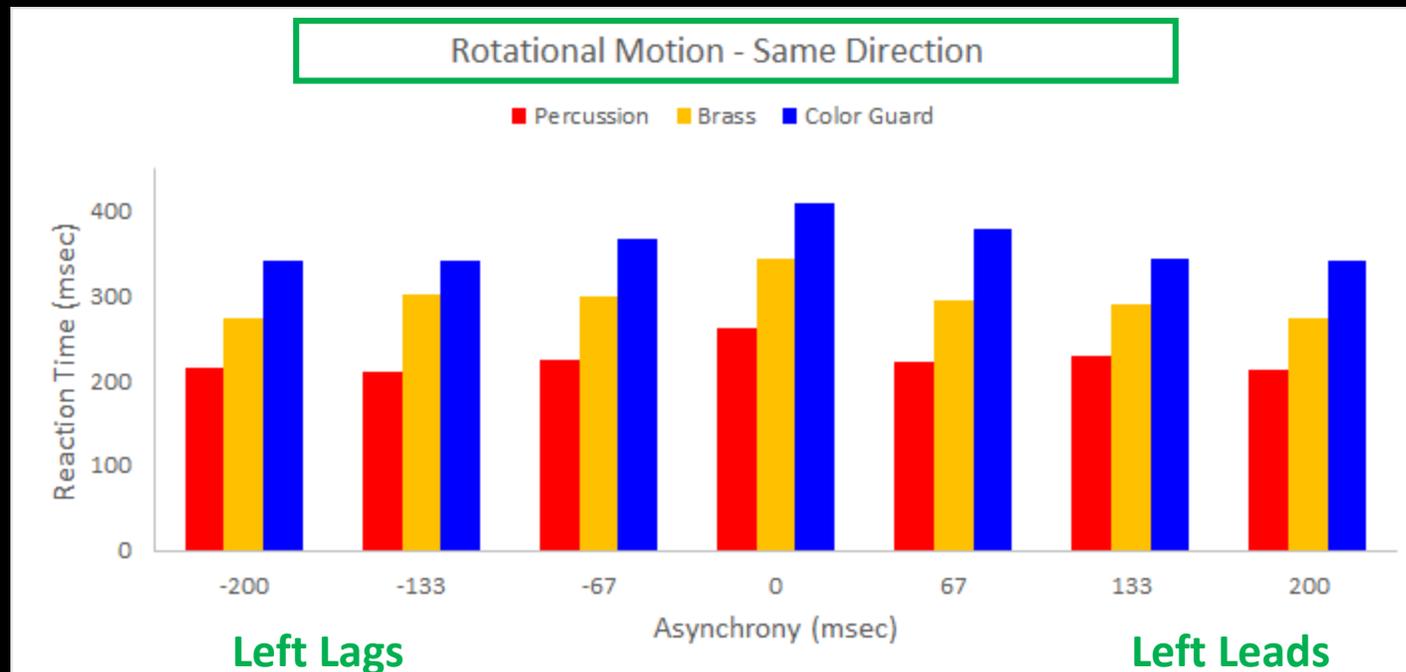
P C B

B C P

B P C

C P B

C B P



$$p = 0.00000357224$$

Group Differences in Reaction Time

6 Permutations

$$p = 1 / 6^7$$

*P B C

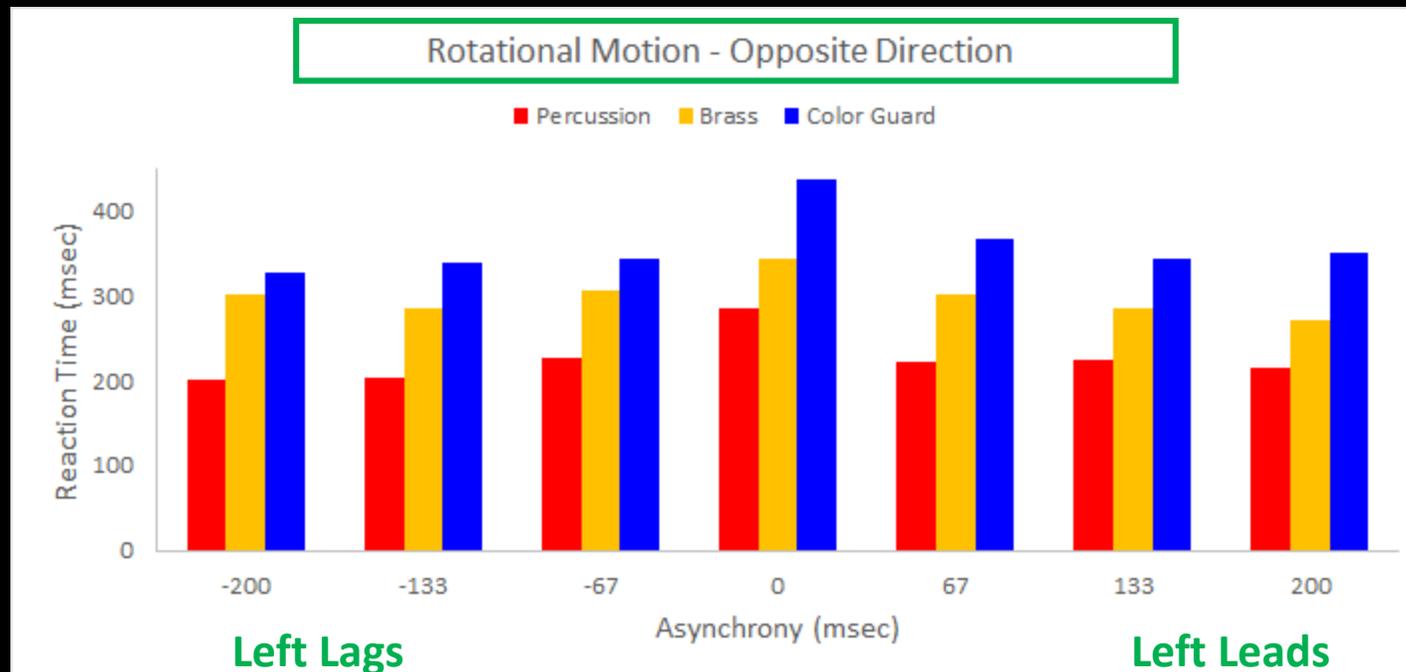
P C B

B C P

B P C

C P B

C B P

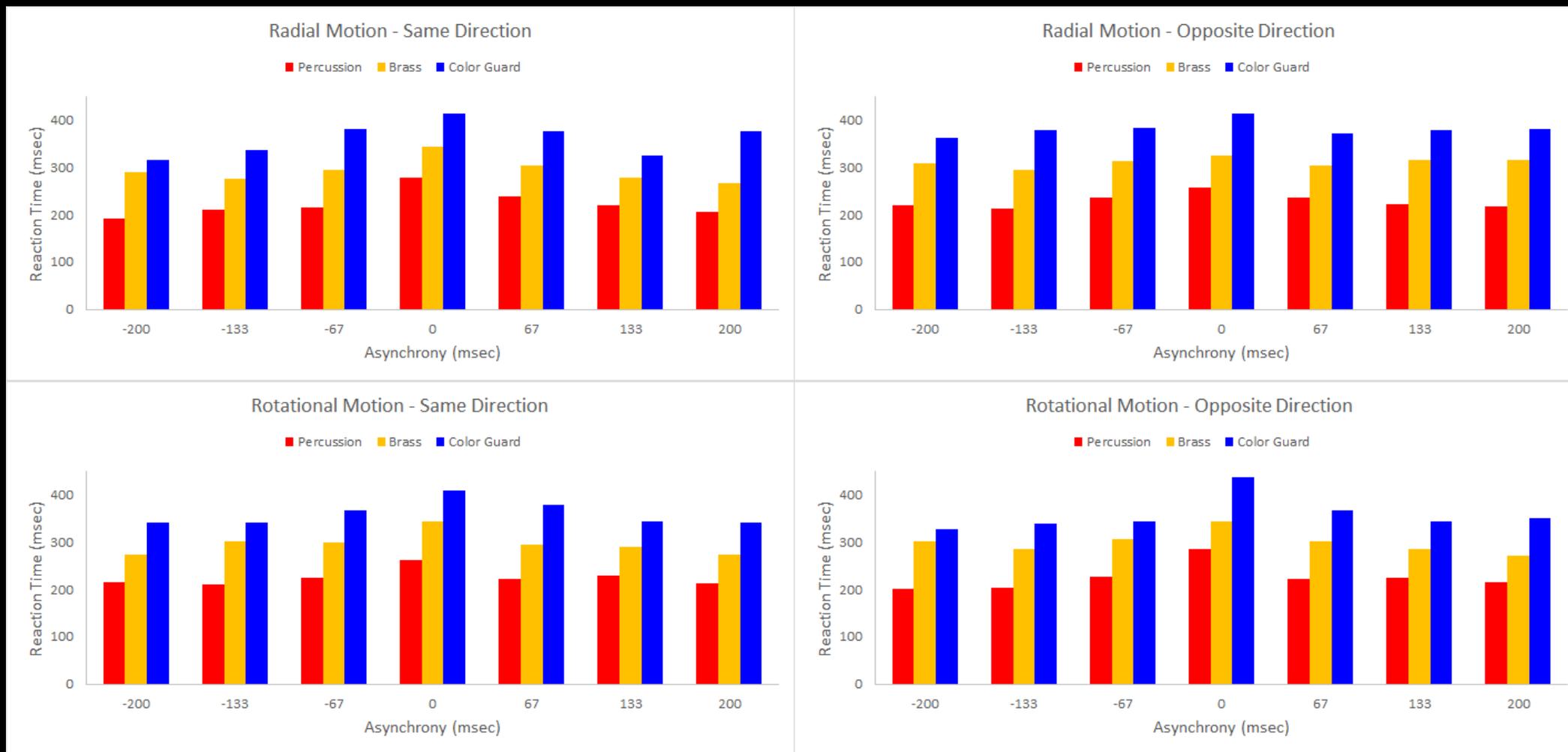


$$p = 0.00000357224$$

Group Differences in Reaction Time

$$p = 1 / 6^7$$

$$p = 1 / 6^7$$



$$p = 1 / 6^7$$

$$p = 1 / 6^7$$

Group Differences Summary

- Reaction Time
 - Percussion < Brass < Color Guard
- Visual Time-Sensitivity
 - Percussion > Brass > Color Guard



Applied Perceptual Learning

Quasi-Experimental Designs – Two Mechanisms

Chopin, Levi & Bavelier, 2017 (Dressmakers show enhanced stereoscopic vision)

1. Self-Selection

2. Plasticity

Take Home Message: Self-Selection

**Drum Corps members self-select into
Color Guard, Brass, and Percussion
by criteria that *co-vary* with
VISUAL timing sensitivity.**

Take Home Message: Plasticity

**VISUALLY defined TOJs
improve more from
AUDITORY (musical) training
than from
VISUAL (color guard) training.**

Thanks To The Bluecoats!



https://en.wikipedia.org/wiki/Bluecoats_Drum_and_Bugle_Corps#/media/File:Bluecoats_large_logo.png

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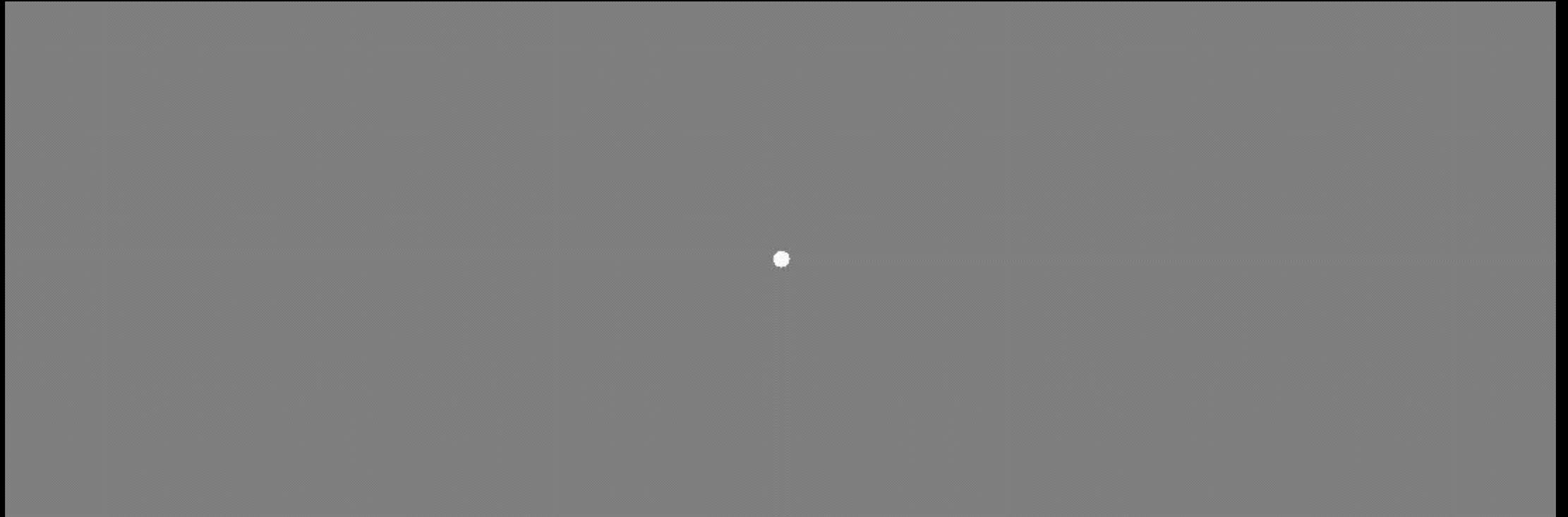
Thank You For Your Attention

References

- Aagten-Murphy, D., Cappagli, G., & Burr, D. (2014).
Chopin, A., Levi, D. M., & Bavelier, D. (2017).
Cicchini, G. M., Arrighi, R., Cecchetti, L., Giusti, M., & Burr, D. C. (2012).
Ortega, L., Guzman-Martinez, E., Grabowecky, M., & Suzuki, S. (2014).

Temporal Order Judgement (TOJ) Task

Rotational Motion – Same Initial Directions ^(a)

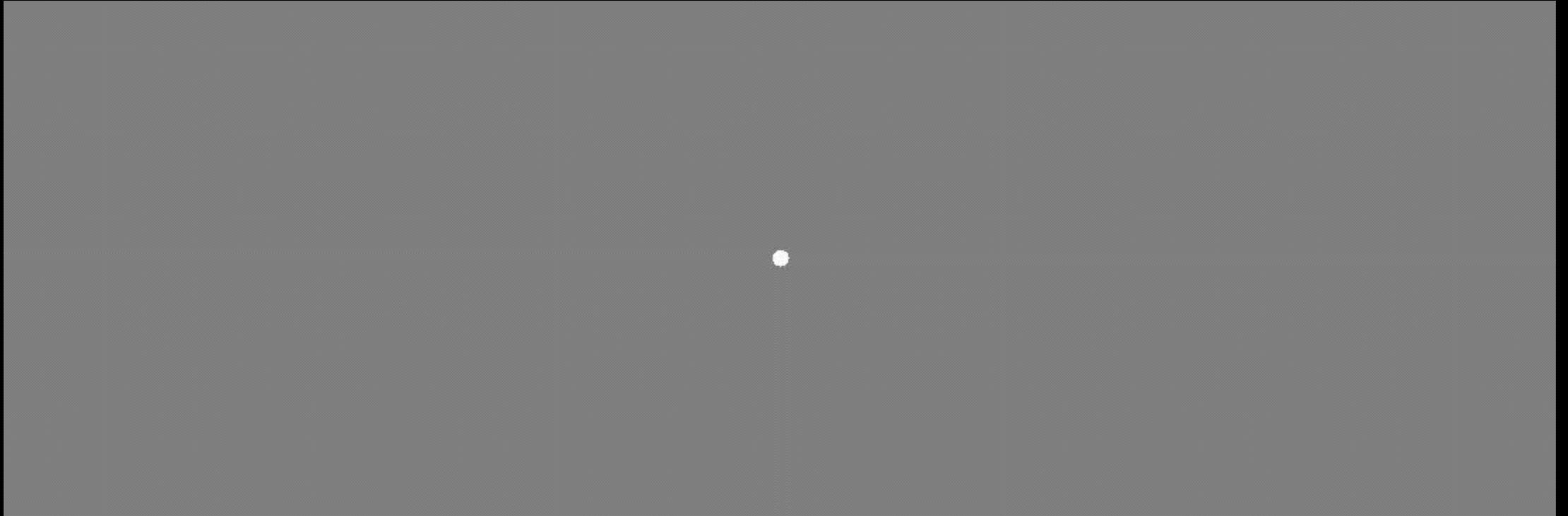


Which side changed direction first?

← Left or Right →

Temporal Order Judgement (TOJ) Task

Rotational Motion – Same Initial Directions ^(b)

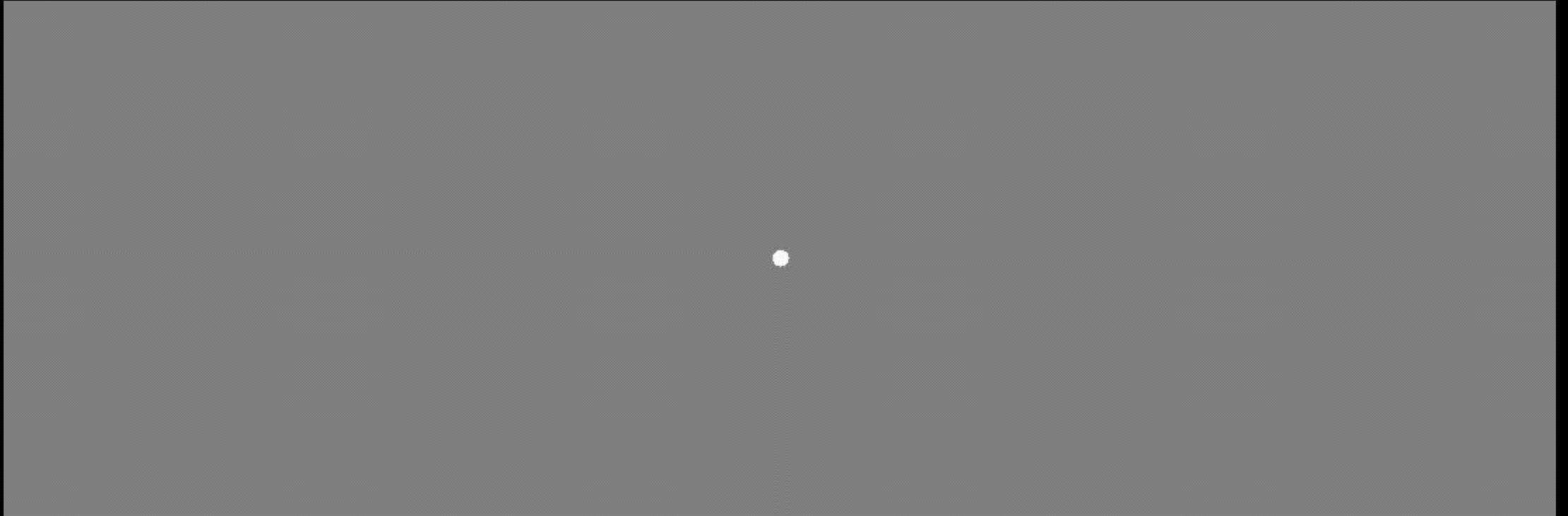


Which side changed direction first?

← Left or Right →

Temporal Order Judgement (TOJ) Task

Rotational Motion – Opposite Initial Directions ^(c)

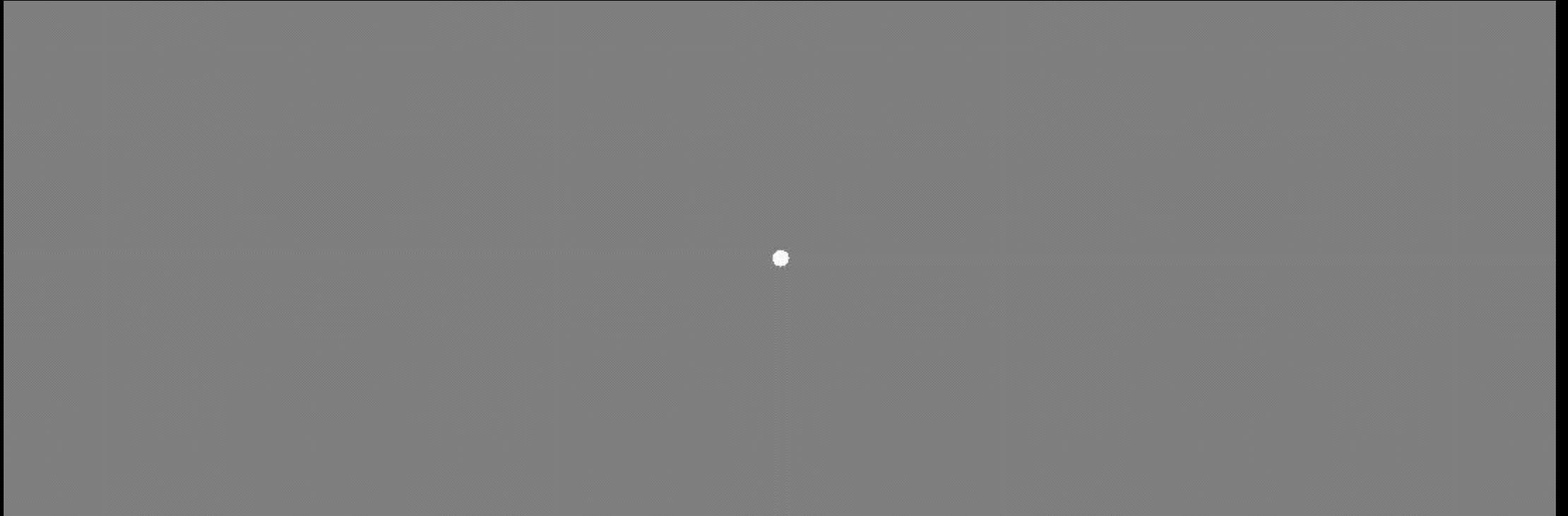


Which side changed direction first?

← Left or Right →

Temporal Order Judgement (TOJ) Task

Rotational Motion – Opposite Initial Directions ^(d)



Which side changed direction first?

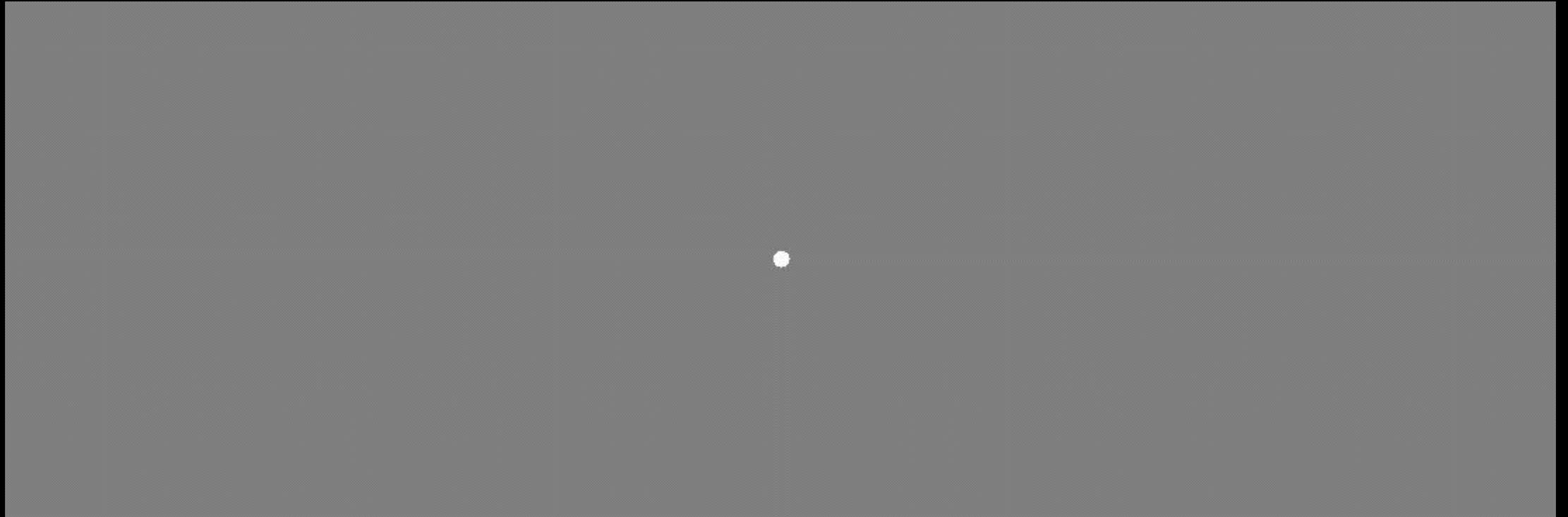
← Left

or

Right →

Temporal Order Judgement (TOJ) Task

Radial Motion – Same Initial Directions ^(e)

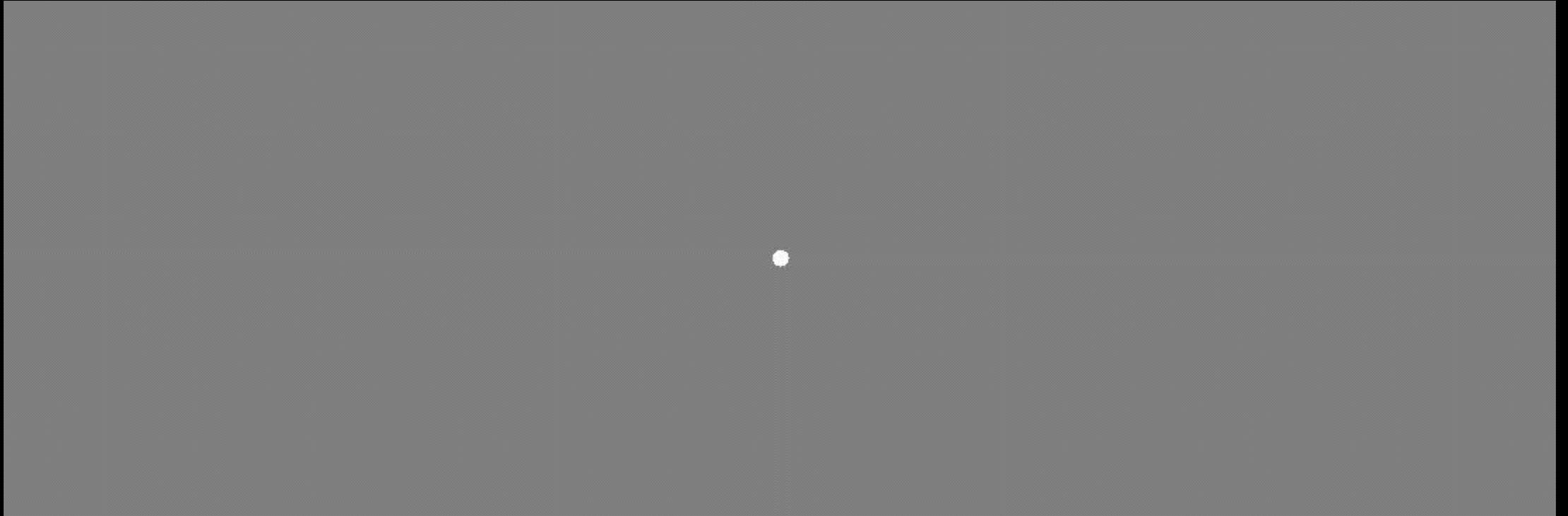


Which side changed direction first?

← Left or Right →

Temporal Order Judgement (TOJ) Task

Radial Motion – Same Initial Directions ^(f)

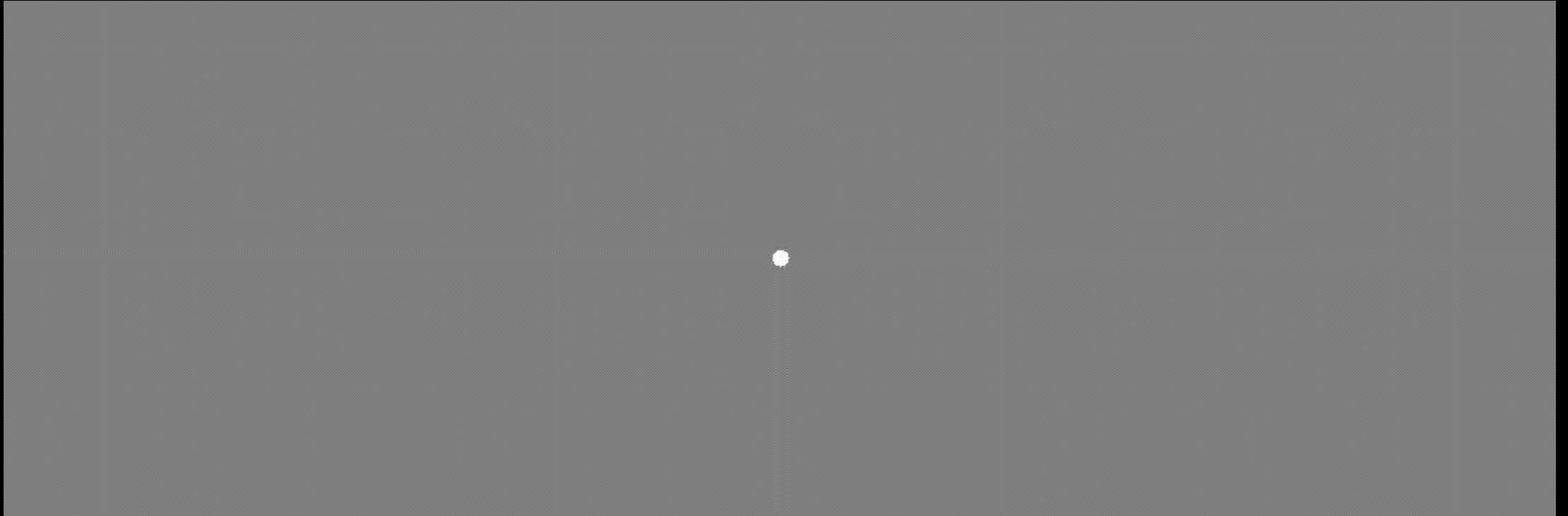


Which side changed direction first?

← Left or Right →

Temporal Order Judgement (TOJ) Task

Radial Motion – Opposite Initial Directions ^(g)

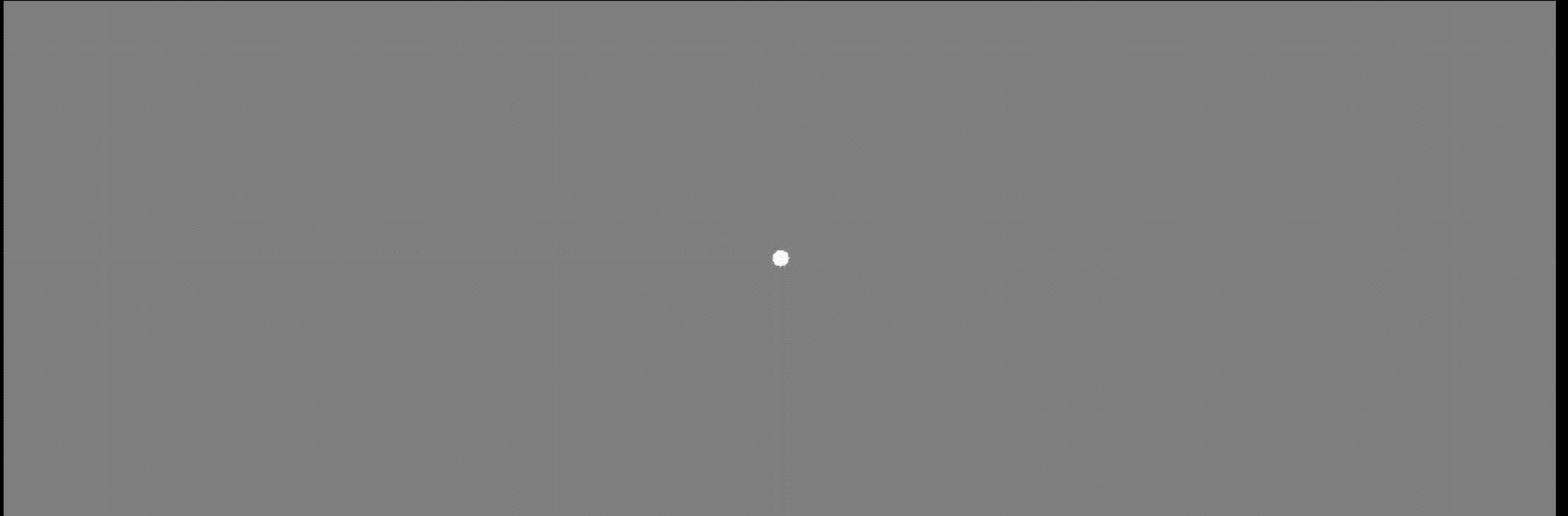


Which side changed direction first?

← Left or Right →

Temporal Order Judgement (TOJ) Task

Radial Motion – Opposite Initial Directions ^(h)



Which side changed direction first?

← Left or Right →

Group Differences in Threshold (JNDs)

Group Differences in Threshold (JNDs)

[Ernst Heinrich Weber](#)

MD Wittenberg 1815

Lectured at Leipzig 1817-71

[Gustav Fechner](#)

BS Leipzig ~1821

No Doctorate

[Rudolf Hermann Lotze](#)

MD PhD Leipzig 1842

[G.E. Muller](#)

PhD Leipzig 1873

Established an Experimental Psych Lab

Gottingen Germany 1881

[William McDougall](#)

MD DSc Cambridge 1898

Studied in G.E. Muller's Lab (1900).

Held the William James Chair at

Harvard 1920-27, then moved to Duke.

[Glenn A. Fry](#)

PhD Duke 1932

[Gerald Westheimer](#)

PhD Ohio State 1952

[Suzanne McKee](#)

PhD Berkeley 1970

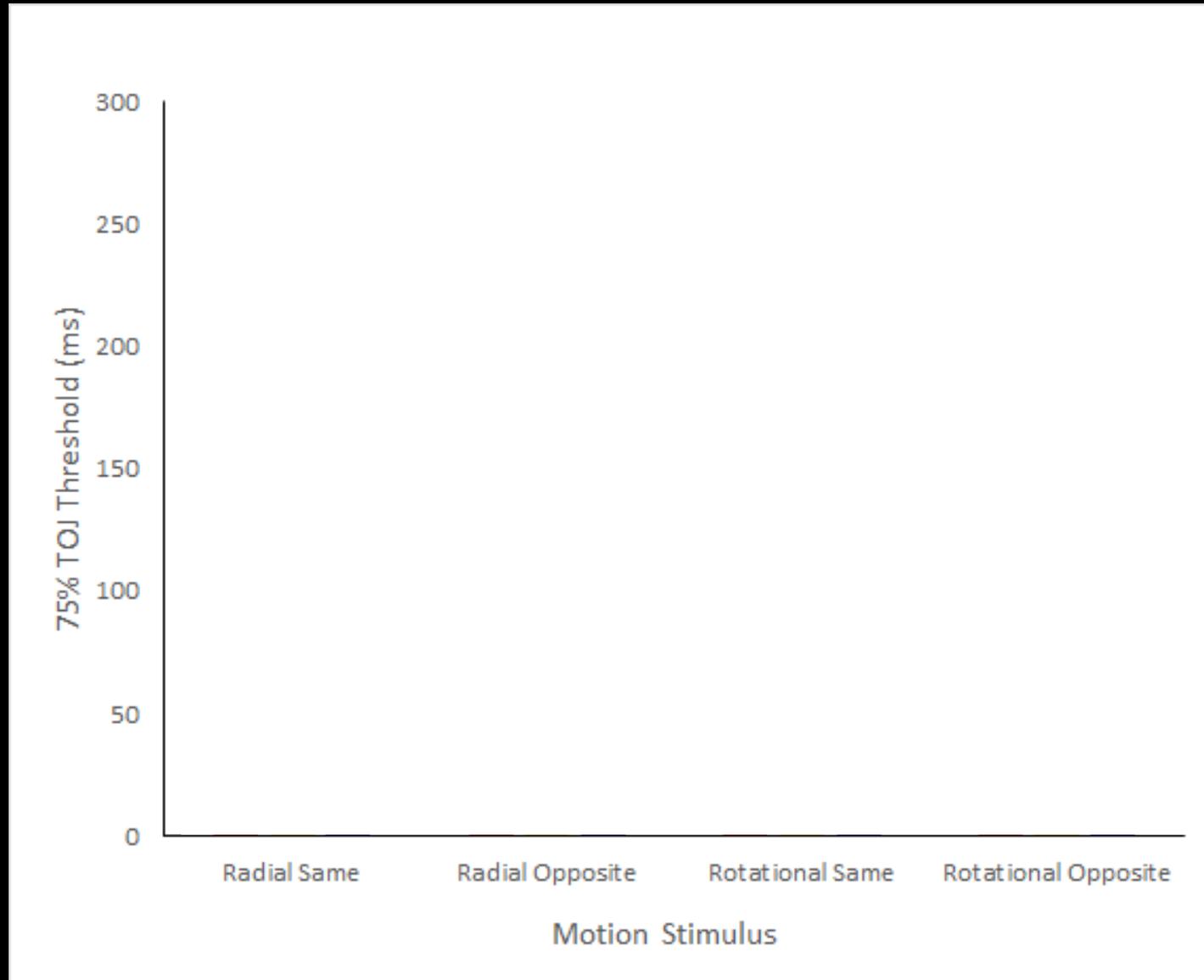
[Leslie Welch](#)

PhD Berkeley 1990

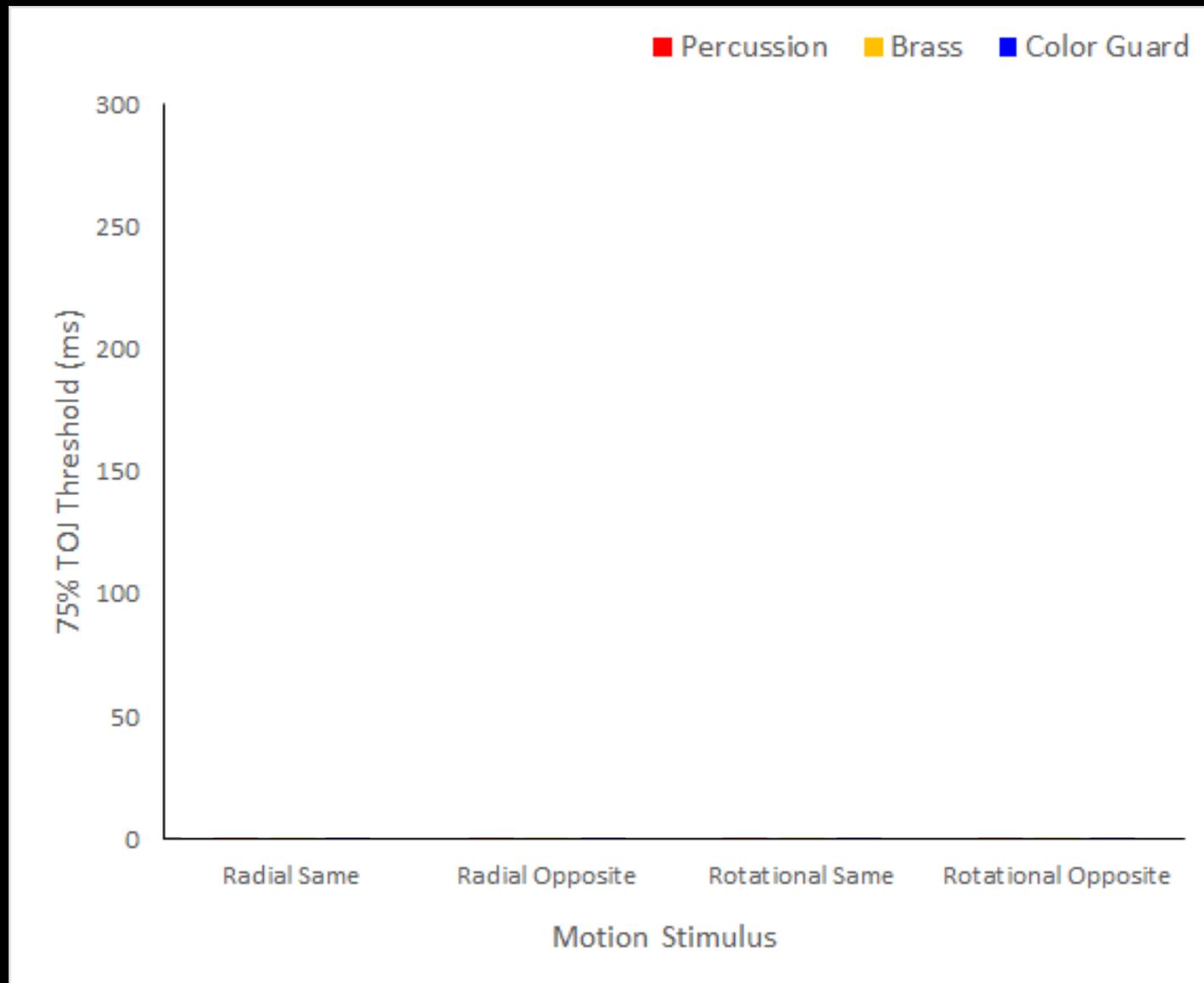
[Nestor Matthews](#)

PhD Brown 1997

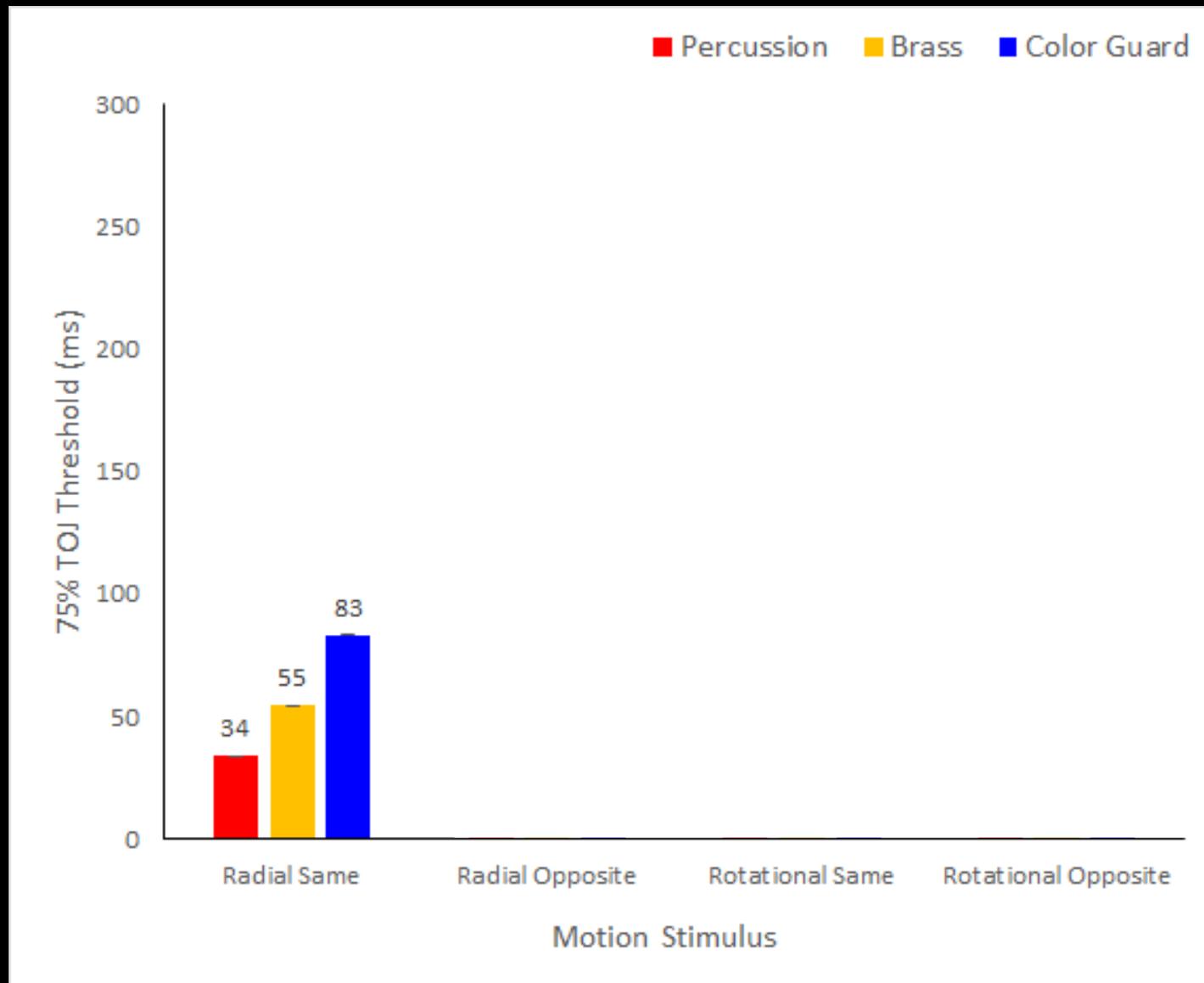
Group Differences in Threshold (JNDs)



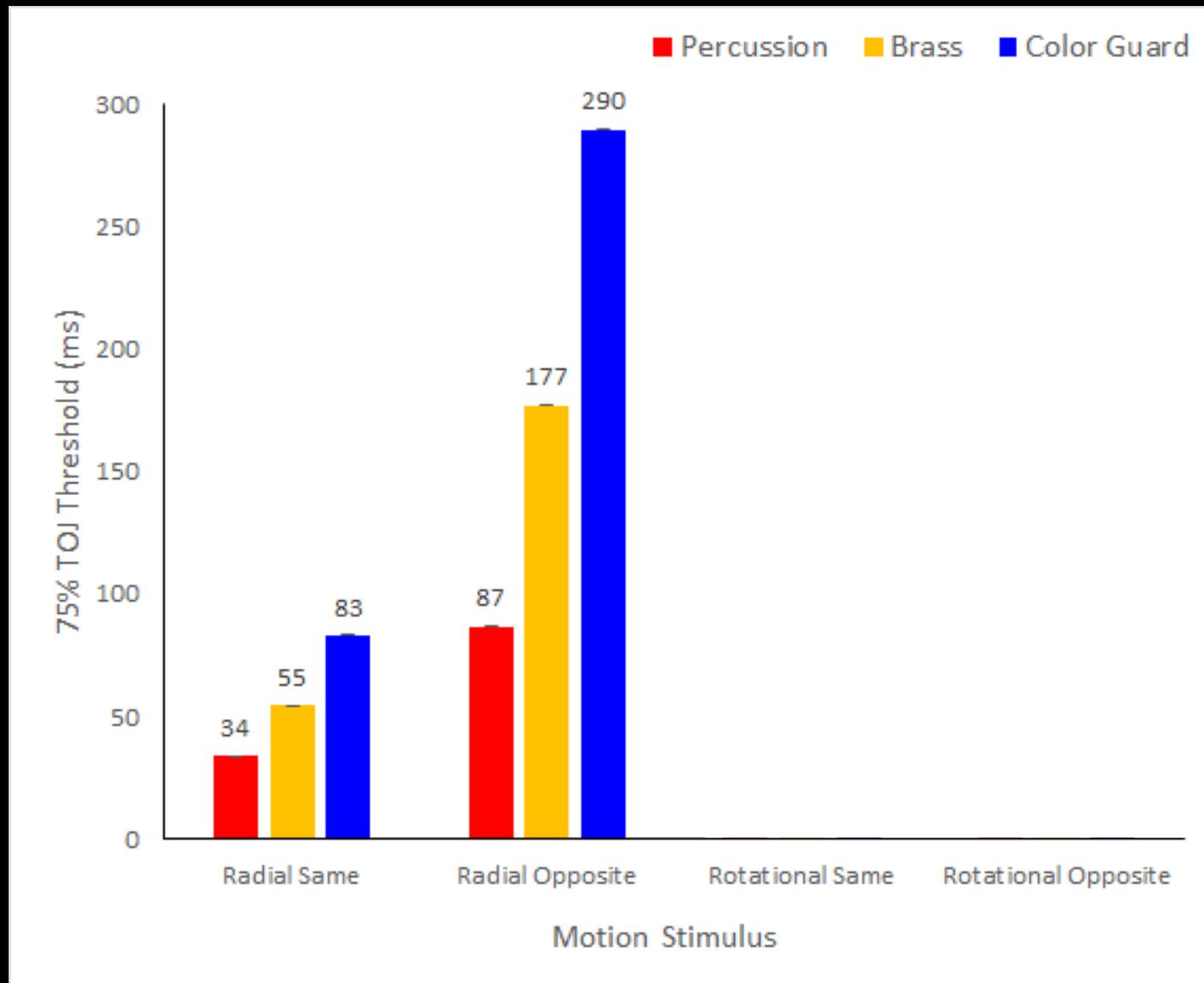
Group Differences in Threshold (JNDs)



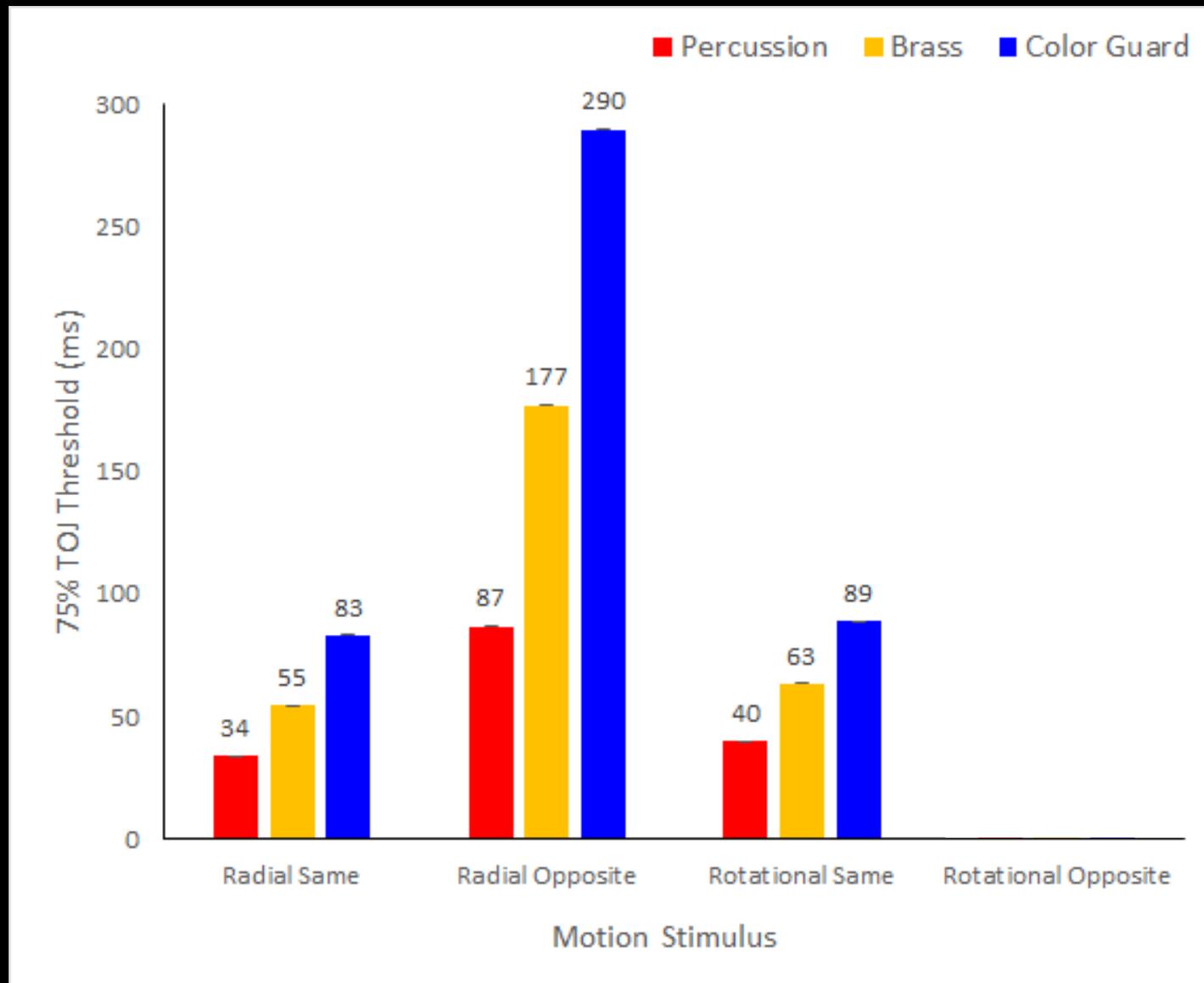
Group Differences in Threshold (JNDs)



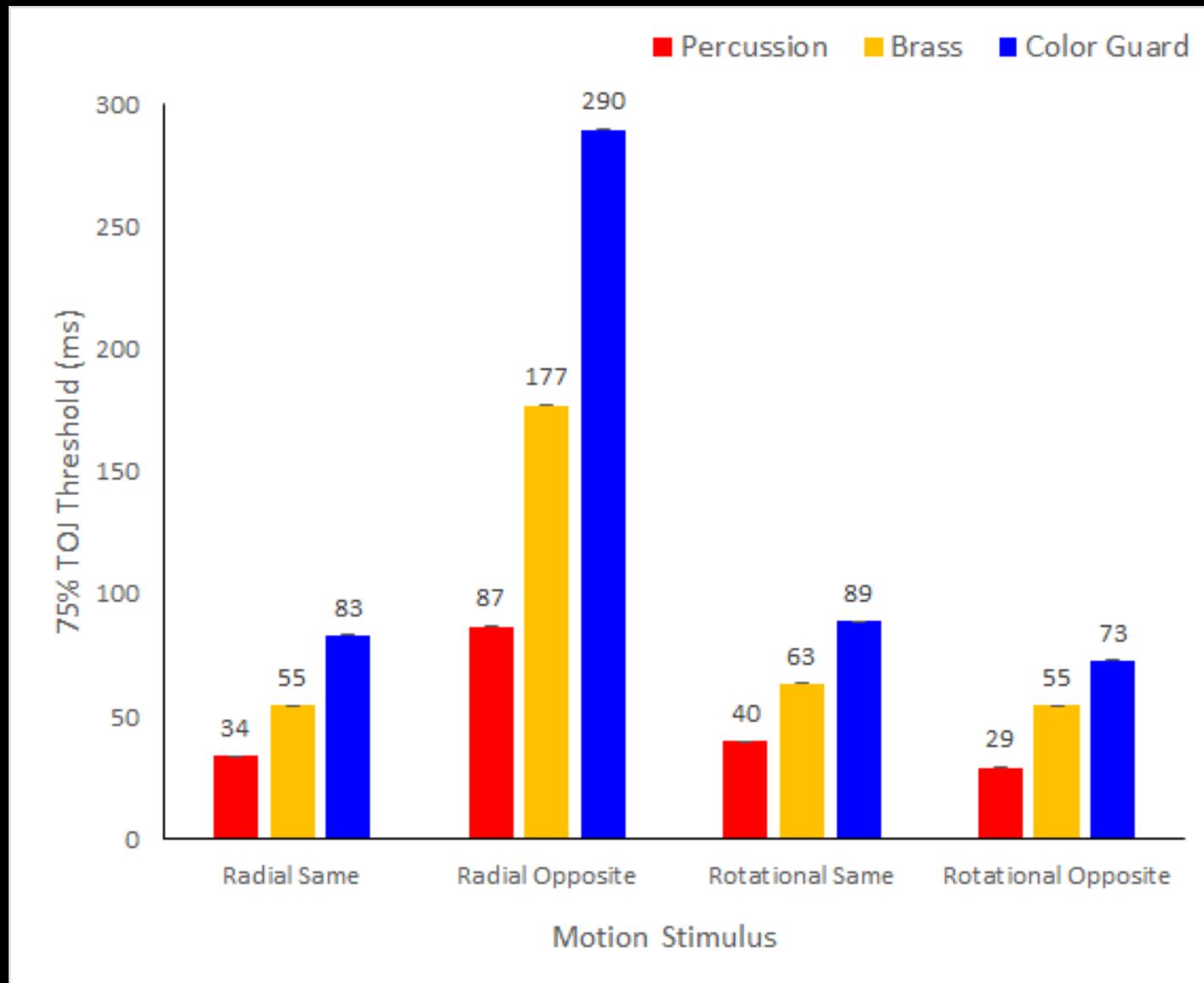
Group Differences in Threshold (JNDs)



Group Differences in Threshold (JNDs)



Group Differences in Threshold (JNDs)



Thresholds in a Musical Context

	Tempo = 180 Beats Per Minute
Beats Per Second	3

Thresholds in a Musical Context

	Tempo = 180 Beats Per Minute
Beats Per Second	3
Milliseconds Per Beat (1/4 th Note)	333.33

Thresholds in a Musical Context

	Tempo = 180 Beats Per Minute
Beats Per Second	3
Milliseconds Per Beat (1/4 th Note)	333.33
Milliseconds Per 8 th Note	166.67

Thresholds in a Musical Context

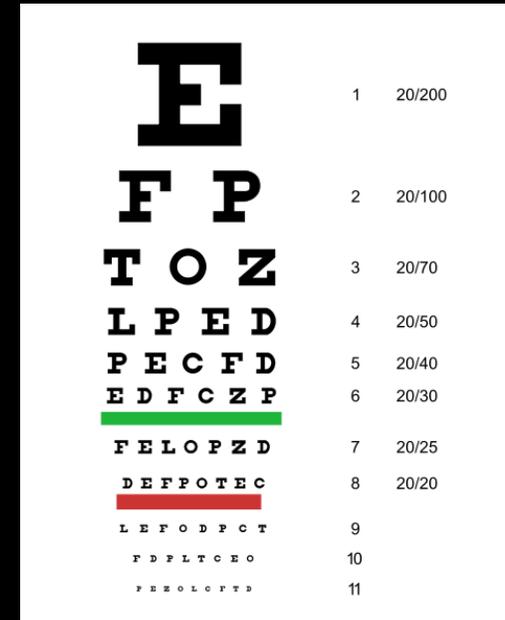
	Tempo = 180 Beats Per Minute
Beats Per Second	3
Milliseconds Per Beat (1/4 th Note)	333.33
Milliseconds Per 8 th Note	166.67
Milliseconds Per 16 th Note	83.33

Thresholds in a Musical Context

	Tempo = 180 Beats Per Minute
Beats Per Second	3
Milliseconds Per Beat (1/4 th Note)	333.33
Milliseconds Per 8 th Note	166.67
Milliseconds Per 16 th Note	83.33
Milliseconds Per 32 nd Note	41.67

Thresholds in a Musical Context

	Tempo = 180 Beats Per Minute
Beats Per Second	3
Milliseconds Per Beat (1/4 th Note)	333.33
Milliseconds Per 8 th Note	166.67
Milliseconds Per 16 th Note	83.33
Milliseconds Per 32 nd Note	41.67



https://commons.wikimedia.org/wiki/File:Snellen_chart.svg

Thresholds in a Musical Context

	Tempo = 180 Beats Per Minute
Beats Per Second	3
Milliseconds Per Beat (1/4 th Note)	333.33
Milliseconds Per 8 th Note	166.67
Milliseconds Per 16 th Note	83.33
Milliseconds Per 32 nd Note	41.67
TF in Hz Per Beat (1/4 th Note)	3
TF in Hz Per 8 th Note	6
TF in Hz Per 16 th Note	12
TF in Hz Per 32 nd Note	24

Thresholds in a Musical Context

	Tempo = 180 Beats Per Minute	Tempo = 120 Beats Per Minute
Beats Per Second	3	2
Milliseconds Per Beat (1/4 th Note)	333.33	500
Milliseconds Per 8 th Note	166.67	250
Milliseconds Per 16 th Note	83.33	125
Milliseconds Per 32 nd Note	41.67	62.5
TF in Hz Per Beat (1/4 th Note)	3	2
TF in Hz Per 8 th Note	6	4
TF in Hz Per 16 th Note	12	8
TF in Hz Per 32 nd Note	24	16

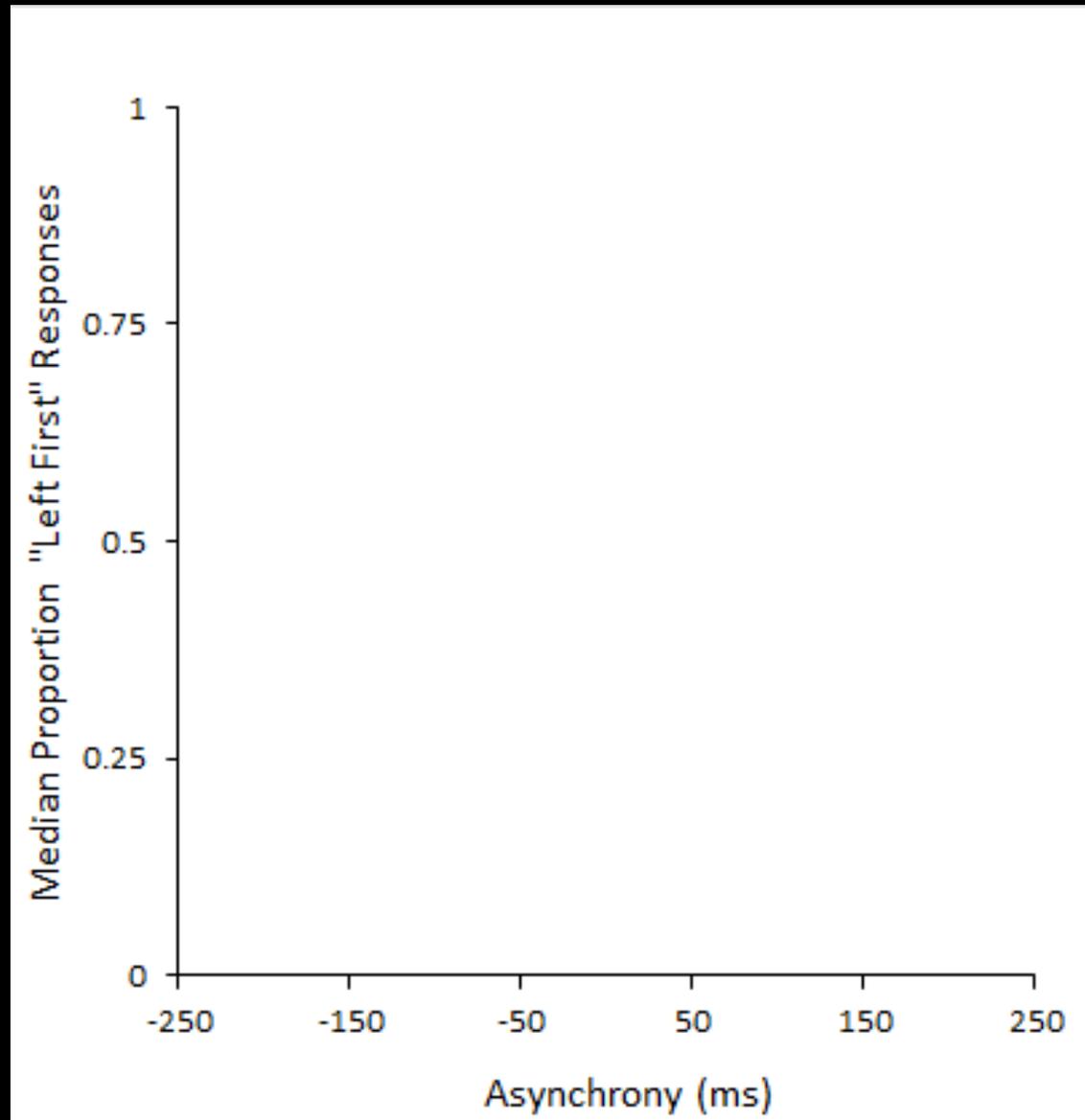
Group Differences Meeting the Inclusion Criterion

Percussionists (100%; 25 / 25)

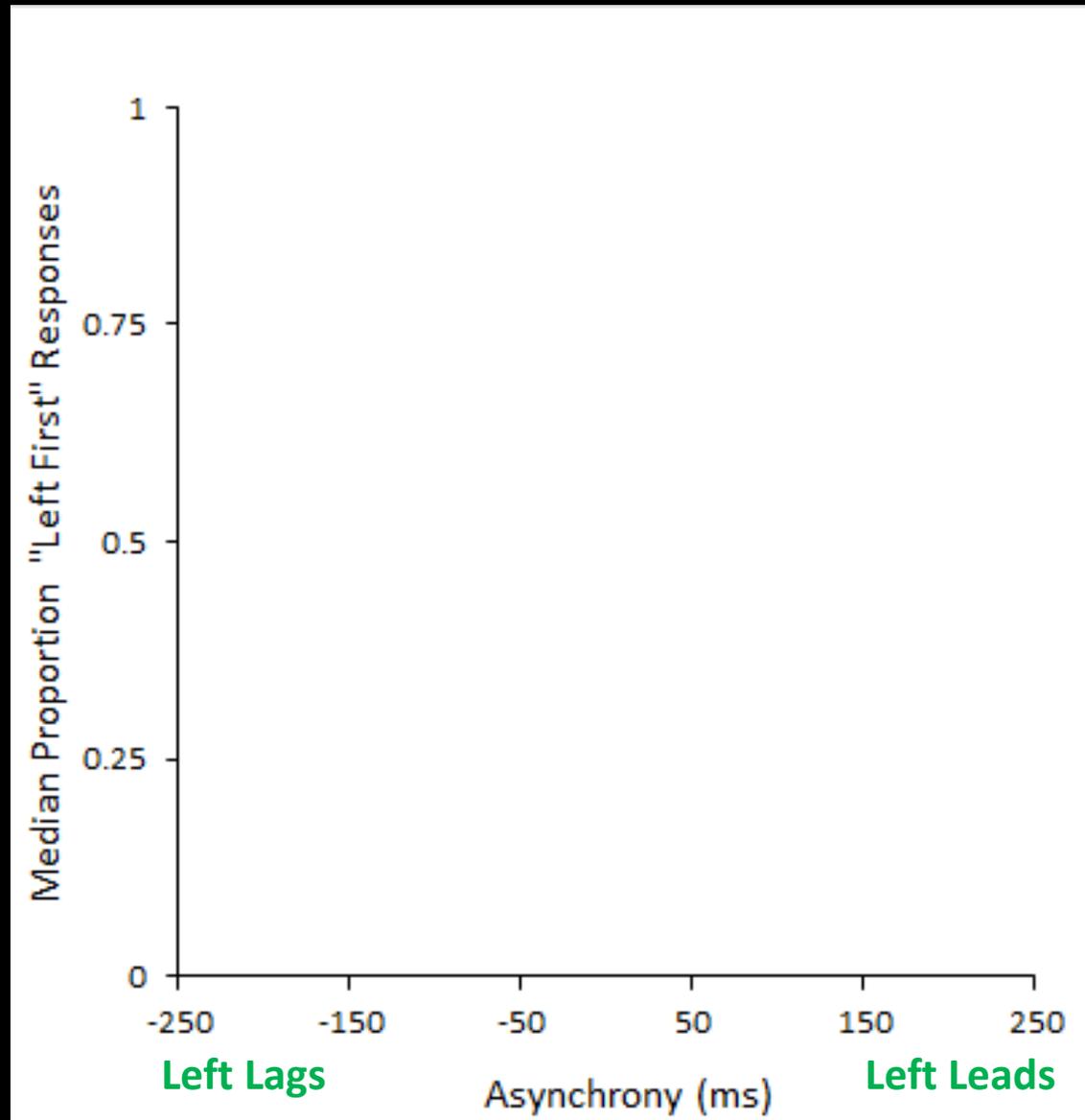
Brass Players (94.4%; 67 / 71)

Color Guard (80.5%; 29 / 36)

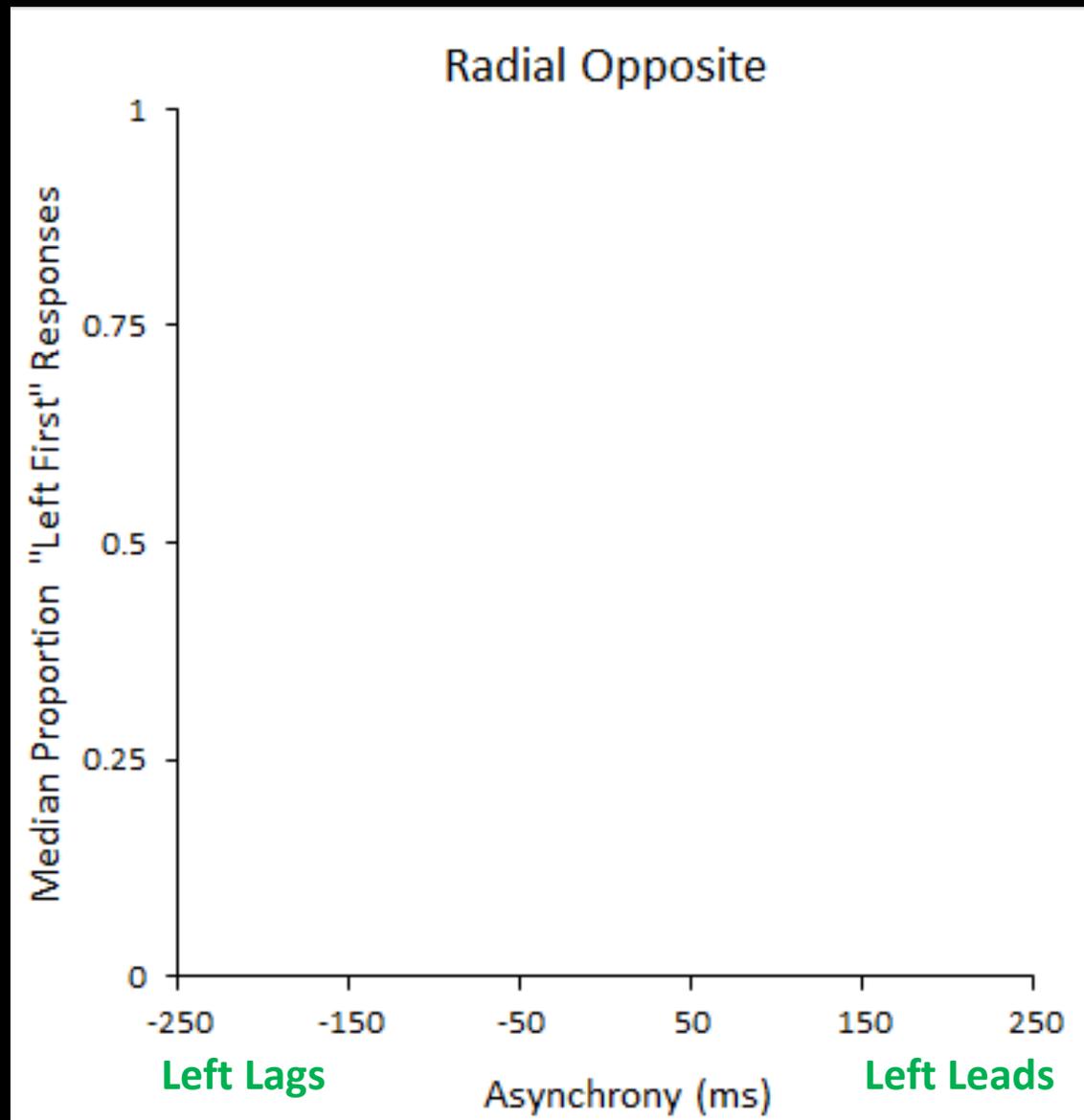
Group Differences in Psychometric Functions



Group Differences in Psychometric Functions

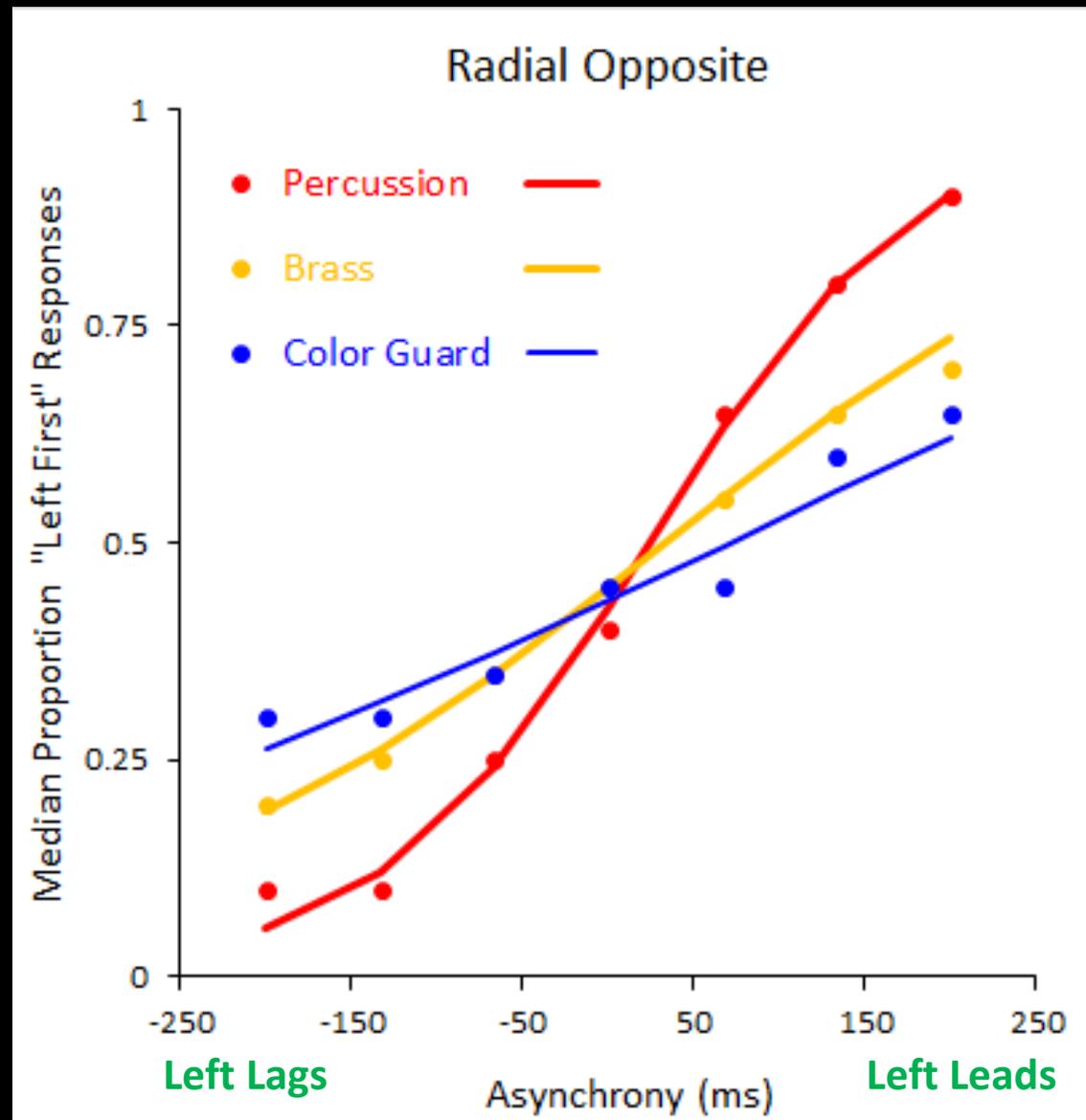


Group Differences in Psychometric Functions



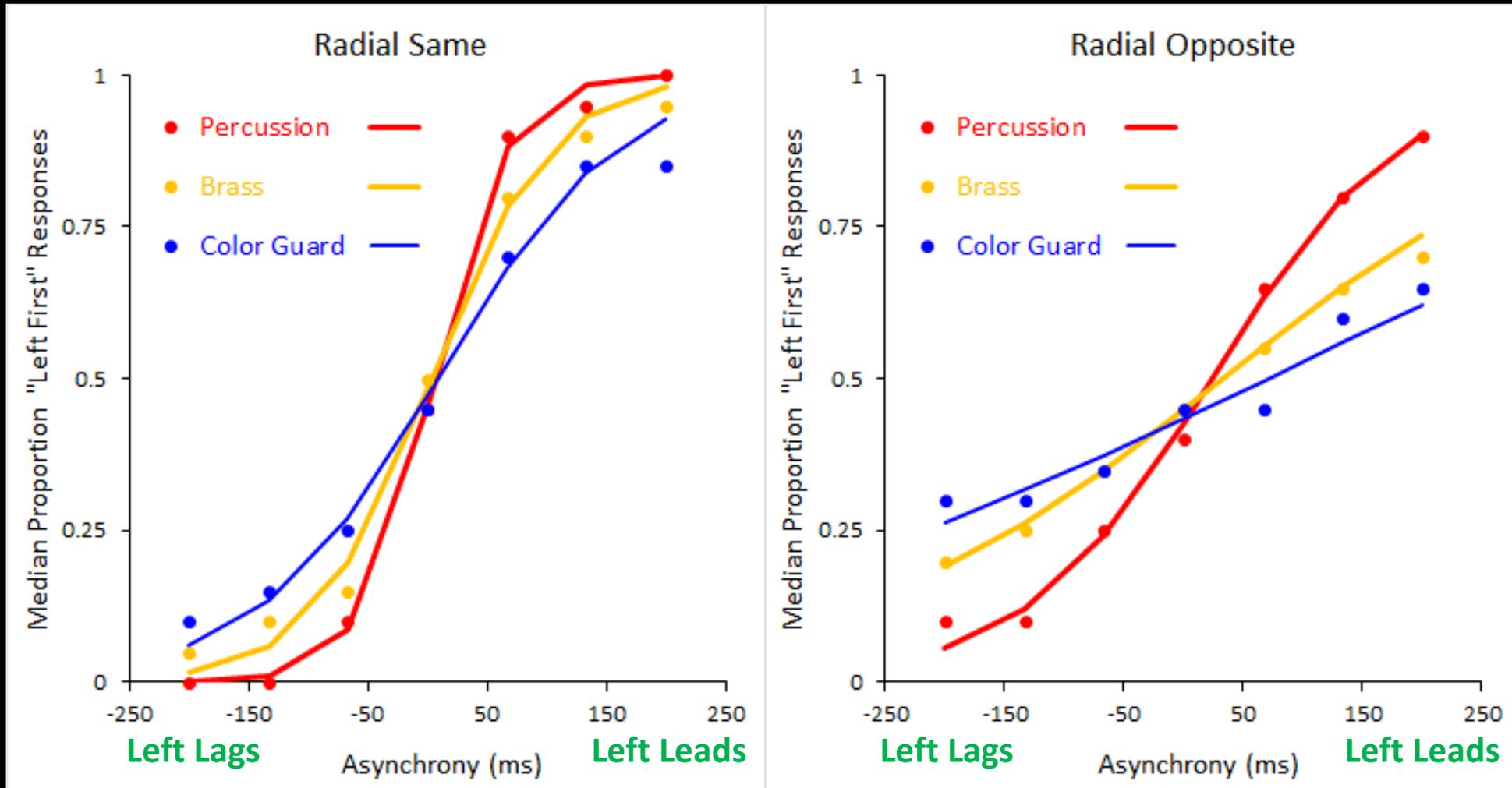
$$\frac{1}{1 + \exp(-K(X - X_0))}$$

Group Differences in Psychometric Functions

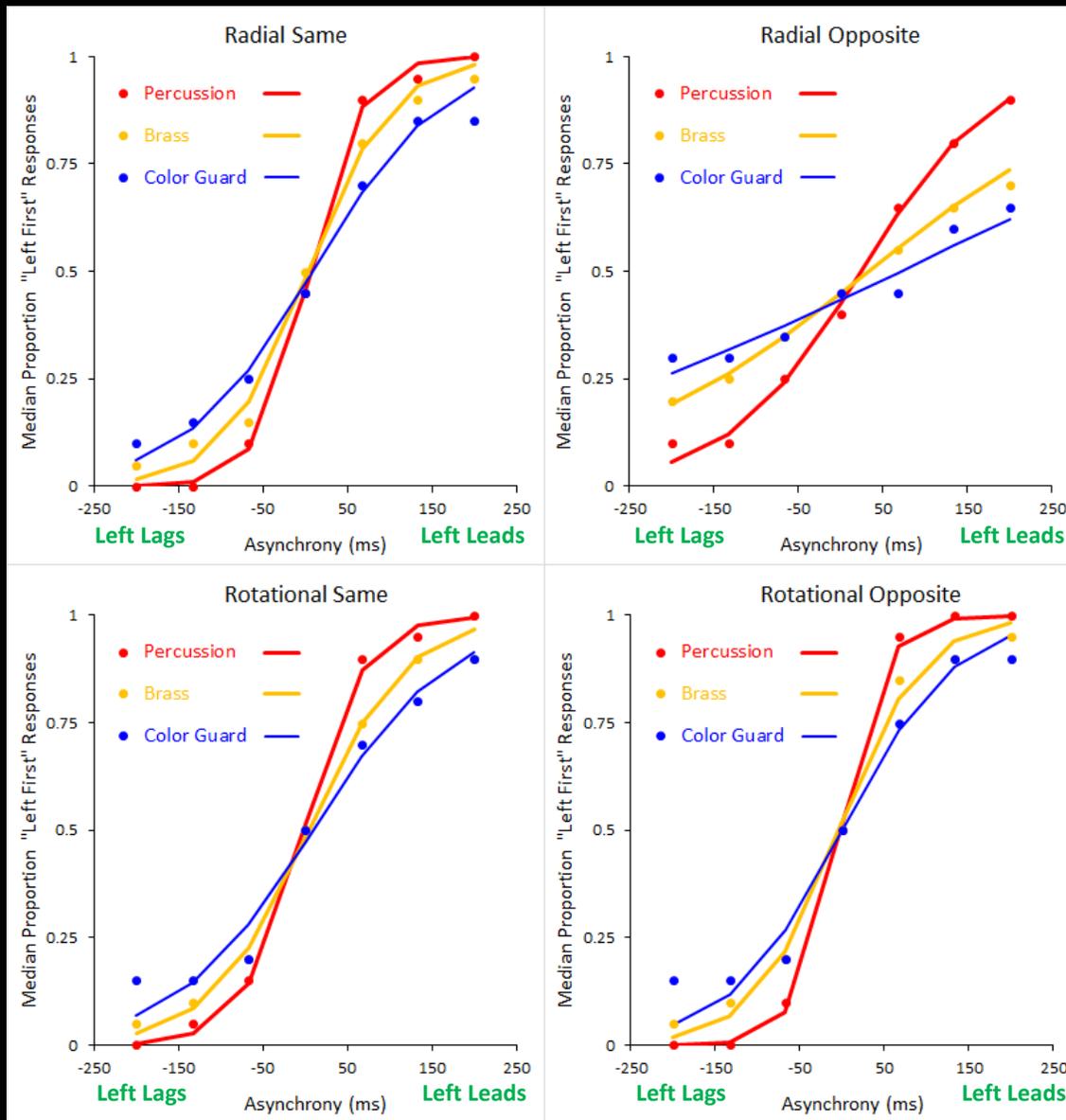


$$\frac{1}{1 + \exp(-K(X - X_0))}$$

Group Differences in Psychometric Functions



Group Differences in Psychometric Functions



$$\frac{1}{1 + \exp(-K(X - X_0))}$$

Relative Ranking Differences within D.C.I.?

Percussionists' DCI Ranking?

Brass Players' DCI Ranking?

Color Guard's DCI Ranking?

DCI 2017 Championship Scores

<https://recaps.competitionsuite.com/1b7406bd-65dc-41b2-b028-f8cac3826e80.htm>

Relative Ranking Differences within D.C.I.?

Percussionists' DCI Ranking?
 Brass Players' DCI Ranking?
 Color Guard's DCI Ranking?



DCI World Championship Finals

Indianapolis, IN

Saturday, August 12, 2017



Chief Judge: John Phillips

World Class

	General Effect														Visual										Music										Penalties										
	General Effect 1							General Effect 2							Visual Proficiency			Visual - Analysis			Color Guard				Music - Brass			Music - Analysis			Music - Percussion				Sub Total	T. DiCarlo	Total								
	M. Gray			M. McGahey				D. Davis			M. Stone				M. Turner		K. Giese			C. Raichle				J. Harper			D. Carbone			A. Dunn		J. Prosperie													
	Rep	Perf	Tot	Rep	Perf	Tot	Tot	Rep	Perf	Tot	Rep	Perf	Tot	Tot	Cont	Achv	Tot	Comp	Achv	Tot	Sbst	Achv	Tot	Tot	Cont	Achv	Tot	Cont	Achv	Tot	Cont	Achv	Tot	Cont	Achv	Tot	Tot								
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1								
Blue Devils	99	98.5	19.75	99	99	19.80	19.775	99	99	19.80	100	100	20.00	19.90	39.675	99	99	19.80	100	100	20.00	98	98	19.60	29.70	97.5	97.5	19.50	97	98	19.30	97	97	19.40	97.5	99	19.65	19.525	29.1625	98.5375	0	98.5375			
Santa Clara Vanguard	98.5	98	19.65	98.5	98	19.65	19.65	98	96	19.40	98	98	19.60	19.50	39.15	98	98	19.60	96	98	19.40	97	96	19.30	29.15	97	96.5	19.35	98	98	19.60	98	98	19.60	98	98	19.60	19.70	19.65	29.30	97.600	0	97.600		
Carolina Crown	96	96	19.20	97	97	19.40	19.30	97	98	19.50	95	94	18.90	19.20	38.50	97	97	19.40	98	99	19.70	93.5	93.5	18.70	28.90	98	98	19.60	99	99	19.80	95	98	19.40	94	95	19.10	93	95	18.80	18.95	29.175	98.575	0	98.575
The Cavaliers	94.5	94.5	18.90	96.5	95	19.15	19.025	96	94.5	19.05	97	95	19.20	19.125	38.15	94	95.5	18.95	97	96	19.30	95.5	94	18.95	28.80	95	94	18.90	95	94	19.00	96	94	19.00	96	96	19.20	19.10	28.45	95.200	0	95.200			
Bluecoats	95	95	19.00	96	96	19.20	19.10	95	95	19.00	96	97	19.30	19.15	38.25	95	96	19.10	95	94	18.90	94	95	18.90	28.45	94	96	19.00	96	95	19.10	94	95	18.90	93.5	94	18.75	18.825	28.4625	95.1625	0	95.1625			
Boston Crusaders	93	92.5	18.55	93	94.5	18.75	18.65	92	91.5	18.35	94	92	18.60	18.475	37.125	93	94	18.70	90	91	18.10	96	95.5	19.15	27.975	93	92	18.50	94	93	18.70	92	93	18.50	93	92.5	18.55	18.525	27.8625	92.8625	0	92.8625			
The Cadets	92	92	18.40	94	93	18.70	18.55	93	93	18.60	91	93	18.40	18.50	37.05	91	89	18.00	92	92	18.40	93	90	18.30	27.35	88.5	90	17.85	92	92	18.40	91	92	18.30	91	92	18.30	18.30	27.275	91.675	0	91.675			
Blue Knights	89	90	17.90	92	91	18.30	18.10	90	90	18.00	88	90	17.80	17.90	36.00	92	90	18.20	89	88	17.70	90	89.5	17.95	26.925	92	88	18.00	93	90	18.30	93	91	18.40	94.5	94.5	18.90	18.65	27.475	90.400	0	90.400			
Phantom Regiment	88	89	17.70	91	89	18.00	17.85	91	87	17.80	89	85	17.40	17.40	35.45	89	86	17.50	86	89	17.50	89	88.5	17.75	26.375	90	85.5	17.55	87	85	17.20	90	90	18.00	89.5	87.5	17.70	17.85	26.30	88.125	0	88.125			
Blue Stars	87.5	88	17.55	89	88.5	17.75	17.65	87	88	17.50	85	88	17.30	17.40	35.05	90	88	17.80	87	86	17.30	92	89	18.10	26.80	89	87	17.60	88	86	17.40	88	86	17.40	89	88.5	17.75	17.575	26.2875	87.9375	0	87.9375			
Crossmen	87	86	17.30	88	88	17.60	17.45	86	86	17.20	86	86	17.20	17.20	34.65	87	87	17.40	85	84	16.90	88	87	17.50	25.90	88	85	17.30	89	88	17.70	89	87	17.60	88	87	17.50	17.55	26.275	86.825	0	86.825			
Madison Scouts	86	85	17.10	86	87	17.30	17.20	88	85	17.30	87	84	17.10	17.20	34.40	83	85	16.80	83	85	16.80	86	85	17.10	25.35	86	84	17.00	86	83	16.90	86	85	17.10	17.10	17.10	25.50	85.250	0	85.250					

* Total reflects factored subcaptions

Relative Ranking Differences within D.C.I.?

Percussionists' DCI Ranking?
 Brass Players' DCI Ranking?
 Color Guard's DCI Ranking?



DCI World Championship Finals

Indianapolis, IN

Saturday, August 12, 2017



Chief Judge: John Phillips

World Class

	General Effect														Visual										Music										Penalties							
	General Effect 1							General Effect 2							Visual Proficiency			Visual - Analysis			Color Guard				Music - Brass			Music - Analysis			Music - Percussion				Sub Total	T. DiCarlo	Total					
	M. Gray			M. McGahey				D. Davis			M. Stone				M. Turner		K. Giese	C. Raichle		J. Harper		D. Carbone	A. Dunn		J. Prosperie																	
	Rep	Perf	Tot	Rep	Perf	Tot	Rep	Perf	Tot	Rep	Perf	Tot	Tot	Cont	Achv	Tot	Comp	Achv	Tot	Sbst	Achv	Tot	Tot	Cont	Achv	Tot	Cont	Achv	Tot	Cont	Achv	Tot	Cont	Achv	Tot	Tot	Pen					
Blue Devils	99 1	98.5 1	19.75 1	99 1	99 1	19.80 1	19.775 1	99 1	99 1	19.80 1	100 1	100 1	20.00 1	19.90 1	39.675 1	99 1	99 1	19.80 1	100 1	100 1	20.00 1	98 1	98 1	19.60 1	29.70 1	97.5 2	97.5 2	19.50 2	97 3	98 3	19.30 3	97 2	97 2	19.40 2	97.5 2	99 1	19.65 2	19.525 2	29.1625 3	98.5375 1	0	98.5375 1
Santa Clara Vanguard	98.5 2	98 2	19.65 2	98.5 2	98 2	19.65 2	19.65 2	98 2	96 3	19.40 3	98 2	98 2	19.60 2	19.50 2	39.15 2	98 2	98 2	19.60 2	96 4	98 3	19.40 3	97 2	96 2	19.30 2	29.15 2	97 3	96.5 3	19.35 3	98 2	98 2	19.60 2	98 1	98 1	19.60 1	99 2	98 2	19.70 2	19.65 1	29.30 1	97.600 2	0	97.600 2
Carolina Crown	96 3	96 3	19.20 3	97 3	97 3	19.40 3	19.30 3	97 3	98 2	19.50 2	94 5	94 5	18.90 5	19.20 3	38.50 3	97 3	97 3	19.40 3	98 2	99 2	19.70 2	93.5 6	93.5 6	18.70 6	28.90 3	98 1	98 1	19.60 1	99 1	99 1	19.80 1	95 4	96 3	19.10 3	93 6	95 4	18.80 5	18.95 4	29.175 2	96.575 3	0	96.575 3
The Cavaliers	94.5 5	94.5 5	18.90 5	96.5 4	95 5	19.15 5	19.025 4	96 4	94.5 5	19.05 5	97 4	95 5	19.20 5	19.125 4	38.15 4	94 5	95.5 5	18.95 5	97 4	98 4	19.30 4	95.5 4	94 5	18.95 5	28.80 4	95 4	94 5	18.90 5	95 4	94 5	19.00 5	96 4	96 4	19.20 4	19.10 4	28.45 5	95.200 4	0	95.200 4			
Bluecoats	95 4	95 4	19.00 4	96 5	96 4	19.20 4	19.10 4	95 5	95 4	19.00 5	96 3	97 3	19.30 3	19.15 4	38.25 4	95 4	96 4	19.10 4	95 5	94 5	18.90 5	94 5	95 4	18.90 5	28.45 5	94 5	96 4	19.00 4	96 4	95 4	19.10 4	94 5	95 4	18.90 5	93.5 5	94 6	18.75 6	18.825 5	28.4625 4	95.1625 5	0	95.1625 5
Boston Crossers	92 6	92 6	18.40 6	93 7	93 6	18.70 6	18.55 6	92 7	91 7	18.60 7	92 6	92 6	18.80 6	18.475 6	37.125 6	92 6	92 6	18.70 6	91 7	91 7	18.70 7	89 8	89 8	18.50 8	27.975 6	92 6	92 6	18.60 6	92 6	92 6	18.80 6	91 7	92 6	18.70 7	18.825 6	27.600 6	92.600 6	0	92.600 6			
The Cadets	92 7	92 7	18.40 7	94 6	93 7	18.70 7	18.55 7	93 6	93 6	18.60 6	91 7	93 8	18.40 7	18.50 6	37.05 7	91 8	89 8	18.00 8	92 6	92 6	18.40 6	93 7	90 7	18.30 7	27.35 7	88.5 10	90 8	17.85 8	92 8	92 7	18.40 7	91 8	92 7	18.30 8	18.30 8	27.275 8	91.675 7	0	91.675 7			
Blue Knights	89 8	90 8	17.90 8	92 8	91 8	18.30 8	18.10 8	90 8	90 8	18.00 8	88 9	90 8	17.80 8	17.90 8	36.00 8	92 7	90 7	18.20 7	89 8	88 9	17.70 8	90 8	89.5 8	17.95 8	26.925 8	92 7	88 8	18.00 7	93 7	90 8	18.30 8	93 6	91 8	18.40 7	94.5 4	94.5 5	18.90 4	18.65 6	27.475 7	90.400 8	0	90.400 8
Phantom Regiment	88 9	89 9	17.70 9	91 9	89 9	18.00 9	17.85 9	91 8	87 10	17.80 9	89 11	85 11	17.40 9	17.60 9	35.45 9	89 10	86 11	17.50 10	86 8	89 10	17.50 9	89 9	88.5 10	17.75 10	26.375 10	90 8	85.5 10	17.55 10	87 11	85 11	17.20 11	90 9	90 9	18.00 9	89.5 9	87.5 10	17.70 9	17.85 9	26.30 9	88.125 9	0	88.125 9
Blue Stars	87.5 10	88 10	17.55 10	89 10	88.5 10	17.75 10	17.65 10	87 11	88 9	17.50 10	85 12	88 9	17.30 10	17.40 10	35.05 10	90 9	88 9	17.80 9	87 8	86 10	17.30 8	92 8	89 8	18.10 8	26.80 9	89 9	87 9	17.60 9	88 10	86 11	17.40 10	88 11	88 11	17.50 11	17.55 10	26.2875 10	87.9375 10	0	87.9375 10			
Crossmen	87 11	86 11	17.30 11	88 11	88 11	17.60 11	17.45 11	86 12	86 11	17.20 12	86 10	86 10	17.20 11	17.20 11	34.65 11	87 11	87 10	17.40 11	85 11	84 12	16.90 11	88 11	87 11	17.50 11	25.90 11	88 11	85 11	17.30 11	89 9	88 10	17.70 10	89 10	87 10	17.60 10	17.50 11	26.275 11	86.825 11	0	86.825 11			
Madison Scouts	88 12	85 12	17.10 12	86 12	87 12	17.30 12	17.20 12	88 10	85 12	17.30 11	87 10	84 12	17.10 12	17.20 12	34.40 12	83 12	85 12	16.80 12	83 12	85 12	16.80 12	86 12	85 12	17.10 12	25.35 12	86 12	84 12	17.00 12	86 12	83 12	16.90 12	86 12	85 12	17.10 12	17.10 12	25.50 12	85.250 12	0	85.250 12			

* Total reflects factored subcaptions

Relative Ranking Differences within D.C.I.?

Percussionists' DCI Ranking → 5th & 6th
 Brass Players' DCI Ranking?
 Color Guard's DCI Ranking?



DCI World Championship Finals

Indianapolis, IN

Saturday, August 12, 2017



Chief Judge: John Phillips

World Class

	General Effect														Visual										Music										Sub Total	Pen	Total								
	General Effect 1							General Effect 2							Visual Proficiency			Visual - Analysis			Color Guard				Music - Brass			Music - Analysis			Music - Percussion														
	M. Gray			M. McGahey				D. Davis			M. Stone				M. Turner		K. Giese	C. Raichle		J. Harper		D. Carbone	A. Dunn		J. Prosperie		Tot	Tot	Tot																
	Rep	Perf	Tot	Rep	Perf	Tot	Tot	Rep	Perf	Tot	Rep	Perf	Tot	Tot	Cont	Achv	Tot	Comp	Achv	Tot	Sbst	Achv	Tot	Tot	Cont	Achv				Tot	Cont	Achv	Tot	Cont				Achv	Tot						
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				1	1	1	1	1				1	1						
Blue Devils	99	98.5	19.75	99	99	19.80	19.775	99	99	19.80	100	100	20.00	19.90	39.675	99	99	19.80	100	100	20.00	98	98	19.60	29.70	97.5	97.5	19.50	97	98	19.30	97	97	19.40	97.5	99	19.65	19.525	29.1625	98.5375	0	98.5375			
Santa Clara Vanguard	98.5	98	19.65	98.5	98	19.65	19.65	98	96	19.40	98	98	19.60	19.50	39.15	98	98	19.60	96	98	19.40	97	96	19.30	29.15	97	96.5	19.35	98	98	19.60	98	98	19.60	98	98	19.60	19.70	19.65	29.30	97.600	0	97.600		
Carolina Crown	96	96	19.20	97	97	19.40	19.30	97	98	19.50	95	94	18.90	19.20	38.50	97	97	19.40	98	99	19.70	93.5	93.5	18.70	28.90	98	98	19.60	99	99	19.80	95	98	19.10	93	95	18.80	18.95	29.175	98.575	0	98.575			
The Cavaliers	94.5	94.5	18.90	96.5	95	19.15	19.025	96	94.5	19.05	97	95	19.20	19.125	38.15	94	95.5	18.95	97	98	19.30	95.5	94	18.95	28.80	95	94	18.90	95	94	18.90	98	94	19.00	96	96	19.20	19.10	28.45	95.200	0	95.200			
Bluecoats	95	95	19.00	96	96	19.20	19.10	95	95	19.00	96	97	19.30	19.15	38.25	95	96	19.10	95	94	18.90	94	95	18.90	28.45	94	96	19.00	96	95	19.10	94	95	19.00	95	94	18.90	93.5	94	18.75	8.825	28.4625	95.1625	0	95.1625
Boston Crossers	92	92	18.40	94	93	18.70	18.55	93	93	18.60	91	93	18.40	18.50	37.05	91	89	18.00	92	92	18.40	93	90	18.30	27.35	88.5	90	17.85	92	92	18.40	91	92	18.30	91	92	18.30	18.30	27.275	91.675	0	91.675			
The Cadets	92	92	18.40	94	93	18.70	18.55	93	93	18.60	91	93	18.40	18.50	37.05	91	89	18.00	92	92	18.40	93	90	18.30	27.35	88.5	90	17.85	92	92	18.40	91	92	18.30	91	92	18.30	18.30	27.275	91.675	0	91.675			
Blue Knights	89	90	17.90	92	91	18.30	18.10	90	90	18.00	88	90	17.80	17.90	36.00	92	90	18.20	89	88	17.70	90	89.5	17.95	26.925	92	88	18.00	93	90	18.30	93	91	18.40	94.5	94.5	18.90	18.65	27.475	90.400	0	90.400			
Phantom Regiment	88	89	17.70	91	89	18.00	17.85	91	87	17.80	89	85	17.40	17.80	35.45	89	86	17.50	86	89	17.50	89	88.5	17.75	26.375	90	85.5	17.55	87	85	17.20	90	90	18.00	89.5	87.5	17.70	17.85	26.30	88.125	0	88.125			
Blue Stars	87.5	88	17.55	89	88.5	17.75	17.65	87	88	17.50	85	88	17.30	17.40	35.05	90	88	17.80	87	86	17.30	92	89	18.10	26.80	89	87	17.60	88	86	17.40	88	86	17.40	89	88.5	17.75	17.575	26.2875	87.9375	0	87.9375			
Crossmen	87	86	17.30	88	88	17.60	17.45	86	86	17.20	86	86	17.20	17.20	34.65	87	87	17.40	85	84	16.90	88	87	17.50	25.90	88	85	17.30	89	88	17.70	89	87	17.60	88	87	17.50	17.55	26.275	88.825	0	88.825			
Madison Scouts	86	85	17.10	86	87	17.30	17.20	88	85	17.30	87	84	17.10	17.20	34.40	83	85	16.80	83	85	16.80	86	85	17.10	25.35	86	84	17.00	86	83	16.90	86	85	17.10	17.10	17.10	25.50	85.250	0	85.250					

* Total reflects factored subcaptions

Relative Ranking Differences within D.C.I.?

Percussionists' DCI Ranking → 5th & 6th
 Brass Players' DCI Ranking → 4th
 Color Guard's DCI Ranking?



DCI World Championship Finals

Indianapolis, IN
 Saturday, August 12, 2017



Chief Judge: John Phillips

World Class

	General Effect														Visual										Music										Sub Total	Pen	Total								
	General Effect 1							General Effect 2							Visual Proficiency			Visual - Analysis			Color Guard				Music - Brass			Music - Analysis			Music - Percussion														
	M. Gray			M. McGahey				D. Davis			M. Stone				M. Turner		K. Giese	C. Raichle		J. Harper		D. Carbone	A. Dunn		J. Prosperie		T. DiCarlo																		
	Rep	Perf	Tot	Rep	Perf	Tot	Tot	Rep	Perf	Tot	Rep	Perf	Tot	Tot	Cont	Achv	Tot	Comp	Achv	Tot	Sbst	Achv	Tot	Tot	Cont	Achv		Tot	Cont	Achv	Tot	Cont	Achv	Tot				Tot							
Blue Devils	99	98.5	19.75	99	99	19.80	19.775	99	99	19.80	100	100	20.00	19.90	39.675	99	99	19.80	100	100	20.00	98	98	19.60	29.70	97.5	97.5	19.50	97	98	19.30	97	97	19.20	97.5	99	19.65	19.525	29.1625	98.5375	0	98.5375			
Santa Clara Vanguard	98.5	98	19.65	98.5	98	19.65	19.65	98	96	19.40	98	98	19.60	19.50	39.15	98	98	19.60	96	98	19.40	97	96	19.30	29.15	97	96.5	19.35	98	98	19.60	98	98	19.60	98	98	19.60	19.65	29.30	97.600	0	97.600			
Carolina Crown	96	96	19.20	97	97	19.40	19.30	97	98	19.50	95	94	18.90	19.20	38.50	97	97	19.40	98	99	19.70	93.5	93.5	18.70	28.90	98	98	19.60	99	99	19.80	95	98	19.10	93	95	18.80	18.95	29.175	96.575	0	96.575			
The Cavaliers	94.5	94.5	18.90	96.5	95	19.15	19.025	96	94.5	19.05	97	95	19.20	19.125	38.15	94	95.5	18.95	97	96	19.30	95.5	94	18.95	28.80	95	94	18.90	95	94	18.90	98	94	19.00	96	96	19.20	19.10	28.45	95.200	0	95.200			
Bluecoats	95	95	19.00	96	96	19.20	19.10	95	95	19.00	96	97	19.30	19.15	38.25	95	96	19.10	95	94	18.90	94	95	18.90	28.45	94	96	19.00	96	95	19.10	94	95	19.00	95	94	18.90	93.5	94	18.75	8.825	28.4625	95.1625	0	95.1625
Boston Crossers	92	92	18.40	94	93	18.70	18.55	93	93	18.60	91	93	18.40	18.50	37.05	91	89	18.00	92	92	18.40	93	90	18.30	27.35	88.5	90	17.85	92	92	18.40	91	92	18.30	91	92	18.30	18.30	27.275	91.675	0	91.675			
The Cadets	92	92	18.40	94	93	18.70	18.55	93	93	18.60	91	93	18.40	18.50	37.05	91	89	18.00	92	92	18.40	93	90	18.30	27.35	88.5	90	17.85	92	92	18.40	91	92	18.30	91	92	18.30	18.30	27.275	91.675	0	91.675			
Blue Knights	89	90	17.90	92	91	18.30	18.10	90	90	18.00	88	90	17.80	17.90	36.00	92	90	18.20	89	88	17.70	90	89.5	17.95	26.925	92	88	18.00	93	90	18.30	93	91	18.40	94.5	94.5	18.90	18.65	27.475	90.400	0	90.400			
Phantom Regiment	88	89	17.70	91	89	18.00	17.85	91	87	17.80	89	85	17.40	17.80	35.45	89	86	17.50	86	89	17.50	89	88.5	17.75	26.375	90	85.5	17.55	87	85	17.20	90	90	18.00	89.5	87.5	17.70	17.85	26.30	88.125	0	88.125			
Blue Stars	87.5	88	17.55	89	88.5	17.75	17.65	87	88	17.50	85	88	17.30	17.40	35.05	90	88	17.80	87	86	17.30	92	89	18.10	26.80	89	87	17.60	88	86	17.40	88	86	17.40	89	88.5	17.75	17.575	26.2875	87.9375	0	87.9375			
Crossmen	87	86	17.30	88	88	17.60	17.45	86	86	17.20	86	86	17.20	17.20	34.65	87	87	17.40	85	84	16.90	88	87	17.50	25.90	88	85	17.30	89	88	17.70	89	87	17.60	88	87	17.50	17.55	26.275	86.825	0	86.825			
Madison Scouts	86	85	17.10	86	87	17.30	17.20	88	85	17.30	87	84	17.10	17.20	34.40	83	85	16.80	83	85	16.80	86	85	17.10	25.35	86	84	17.00	86	83	16.90	86	85	17.10	17.10	17.10	25.50	85.250	0	85.250					

* Total reflects factored subcaptions

Relative Ranking Differences within D.C.I.?

Percussionists' DCI Ranking → 5th & 6th

Brass Players' DCI Ranking → 4th

Color Guard's DCI Ranking → 5th



DCI World Championship Finals

Indianapolis, IN

Saturday, August 12, 2017



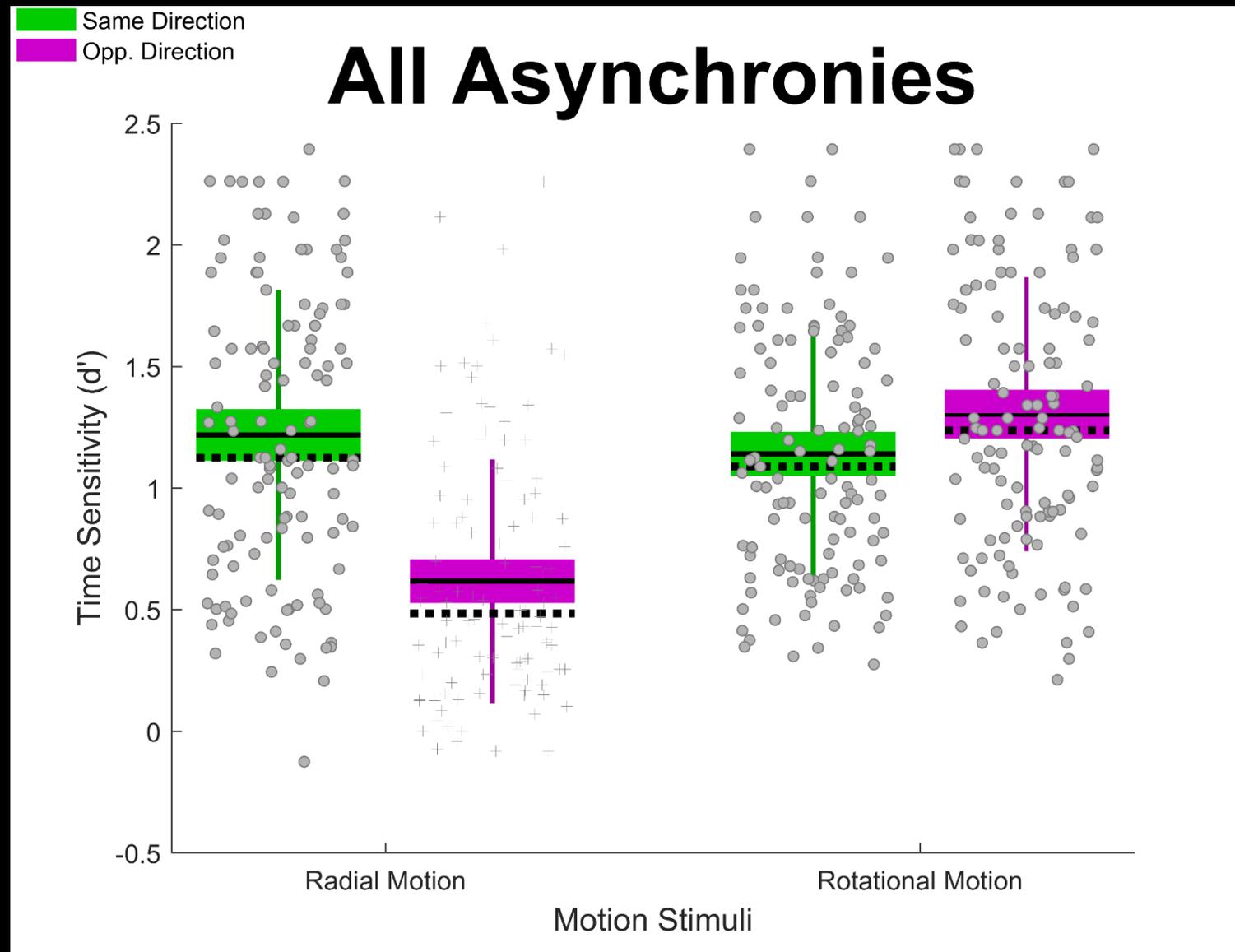
Chief Judge: John Phillips

World Class

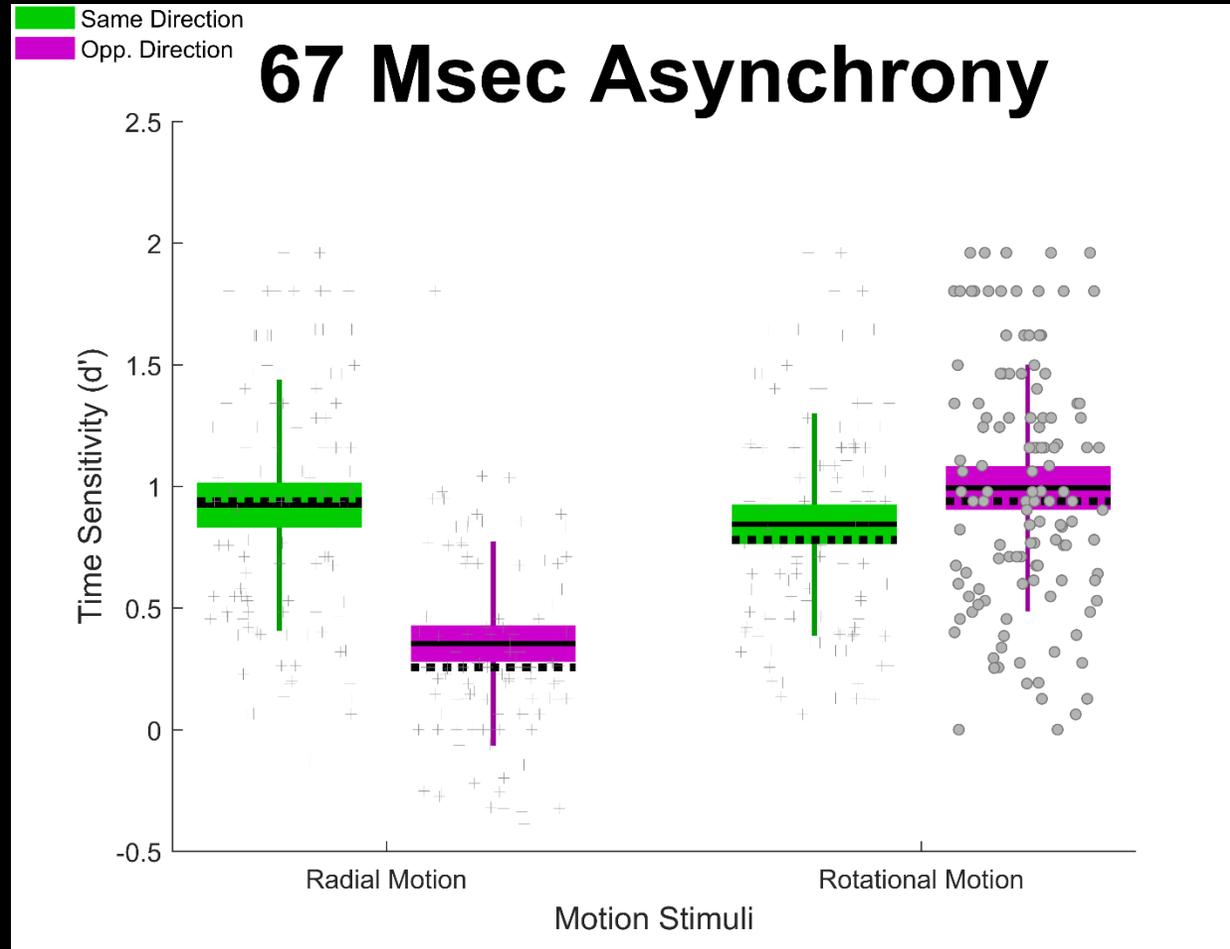
	General Effect														Visual										Music										Penalties							
	General Effect 1							General Effect 2							Visual Proficiency			Visual - Analysis			Color Guard				Music - Brass			Music - Analysis			Music - Percussion				Sub Total	T. DiCarlo	Total					
	M. Gray			M. McGahey				D. Davis			M. Stone				M. Turner		K. Giese	C. Raichle		J. Harper		D. Carbone	A. Dunn		J. Prosperie																	
	Rep	Perf	Tot	Rep	Perf	Tot	Rep	Perf	Tot	Rep	Perf	Tot	Tot	Cont	Achv	Tot	Comp	Achv	Tot	Sbst	Achv	Tot	Tot	Cont	Achv	Tot	Cont	Achv	Tot	Cont	Achv	Tot	Cont	Achv	Tot	Tot	Pen					
Blue Devils	99	98.5	19.75	99	99	19.80	19.775	99	99	19.80	100	100	20.00	19.90	39.675	99	99	19.80	100	100	20.00	98	98	19.60	29.70	97.5	97.5	19.50	97	98	19.30	97	97	19.40	97.5	99	19.65	19.525	29.1625	98.5375	0	98.5375
Santa Clara Vanguard	98.5	98	19.65	98.5	98	19.65	19.65	98	96	19.40	98	98	19.60	19.50	39.15	98	98	19.60	96	98	19.40	97	96	19.30	29.15	97	96.5	19.35	98	98	19.60	98	98	19.60	98	98	19.60	19.60	29.30	97.600	0	97.600
Carolina Crown	96	96	19.20	97	97	19.40	19.30	97	98	19.50	95	94	18.90	19.20	38.50	97	97	19.40	98	99	19.70	93.5	93.5	18.70	28.90	98	98	19.60	99	99	19.80	95	96	19.10	93	95	18.80	18.95	29.175	96.575	0	96.575
The Cavaliers	94.5	94.5	18.90	96.5	95	19.15	19.025	96	94.5	19.05	97	95	19.20	19.125	38.15	94	95.5	18.95	97	96	19.30	95.5	94	18.95	28.80	95	94	18.90	95	94	18.90	96	94	19.00	96	96	19.20	19.10	28.45	95.200	0	95.200
Bluecoats	95	95	19.00	96	96	19.20	19.10	95	95	19.00	96	97	19.30	19.15	38.25	95	96	19.10	95	94	18.90	94	95	18.90	38.45	94	96	19.00	96	95	19.10	94	95	18.90	93.5	94	18.75	8.825	28.4625	95.1625	0	95.1625
Boston Crossers	92	92	18.40	94	93	18.70	18.55	93	93	18.60	91	93	18.40	18.50	37.05	91	89	18.00	92	92	18.40	93	90	18.30	27.35	88.5	90	17.85	92	92	18.40	91	92	18.30	91	92	18.30	27.275	91.675	0	91.675	
The Cadets	92	92	18.40	94	93	18.70	18.55	93	93	18.60	91	93	18.40	18.50	37.05	91	89	18.00	92	92	18.40	93	90	18.30	27.35	88.5	90	17.85	92	92	18.40	91	92	18.30	91	92	18.30	27.275	91.675	0	91.675	
Blue Knights	89	90	17.90	92	91	18.30	18.10	90	90	18.00	88	90	17.80	17.90	36.00	92	90	18.20	89	88	17.70	90	89.5	17.95	26.925	92	88	18.00	93	90	18.30	93	91	18.40	94.5	94.5	18.90	18.65	27.475	90.400	0	90.400
Phantom Regiment	88	89	17.70	91	89	18.00	17.85	91	87	17.80	89	85	17.40	17.80	35.45	89	86	17.50	86	89	17.50	89	88.5	17.75	26.375	90	85.5	17.55	87	85	17.20	90	90	18.00	89.5	87.5	17.70	17.85	26.30	88.125	0	88.125
Blue Stars	87.5	88	17.55	89	88.5	17.75	17.65	87	88	17.50	85	88	17.30	17.40	35.05	90	88	17.80	87	86	17.30	92	89	18.10	26.80	89	87	17.60	88	86	17.40	88	86	17.40	89	88.5	17.75	17.575	26.2875	87.9375	0	87.9375
Crossmen	87	86	17.30	88	88	17.60	17.45	86	86	17.20	86	86	17.20	17.20	34.65	87	87	17.40	85	84	16.90	88	87	17.50	25.90	88	85	17.30	89	88	17.70	89	87	17.60	88	87	17.50	17.65	26.275	86.825	0	86.825
Madison Scouts	86	85	17.10	86	87	17.30	17.20	88	85	17.30	87	84	17.10	17.20	34.40	83	85	16.80	83	85	16.80	86	85	17.10	25.35	86	84	17.00	86	83	16.90	86	85	17.10	17.10	25.50	85.250	0	85.250			

* Total reflects factored subcaptions

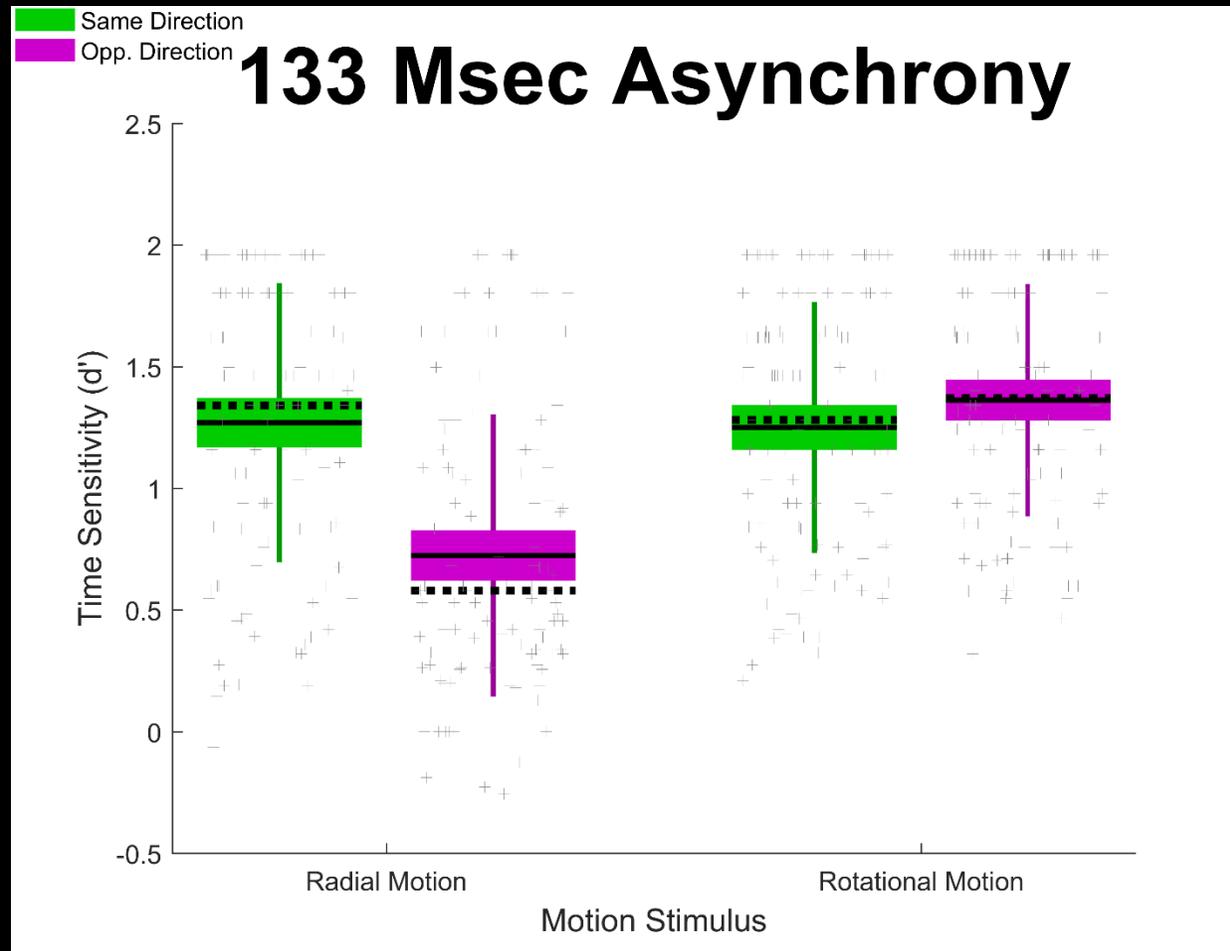
Interaction Between Motion-Type and Initial-Directions



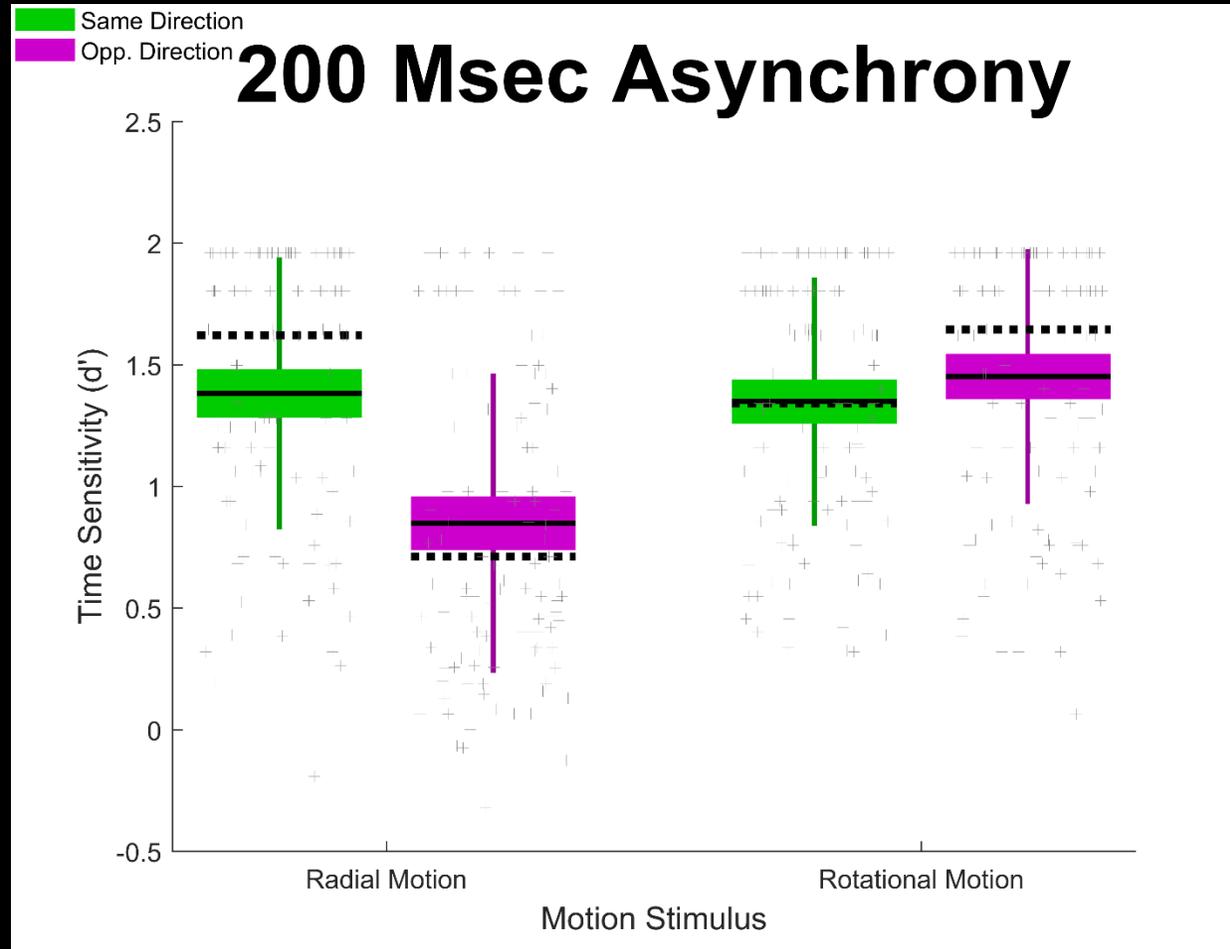
Interaction Between Motion-Type and Initial-Directions



Interaction Between Motion-Type and Initial-Directions



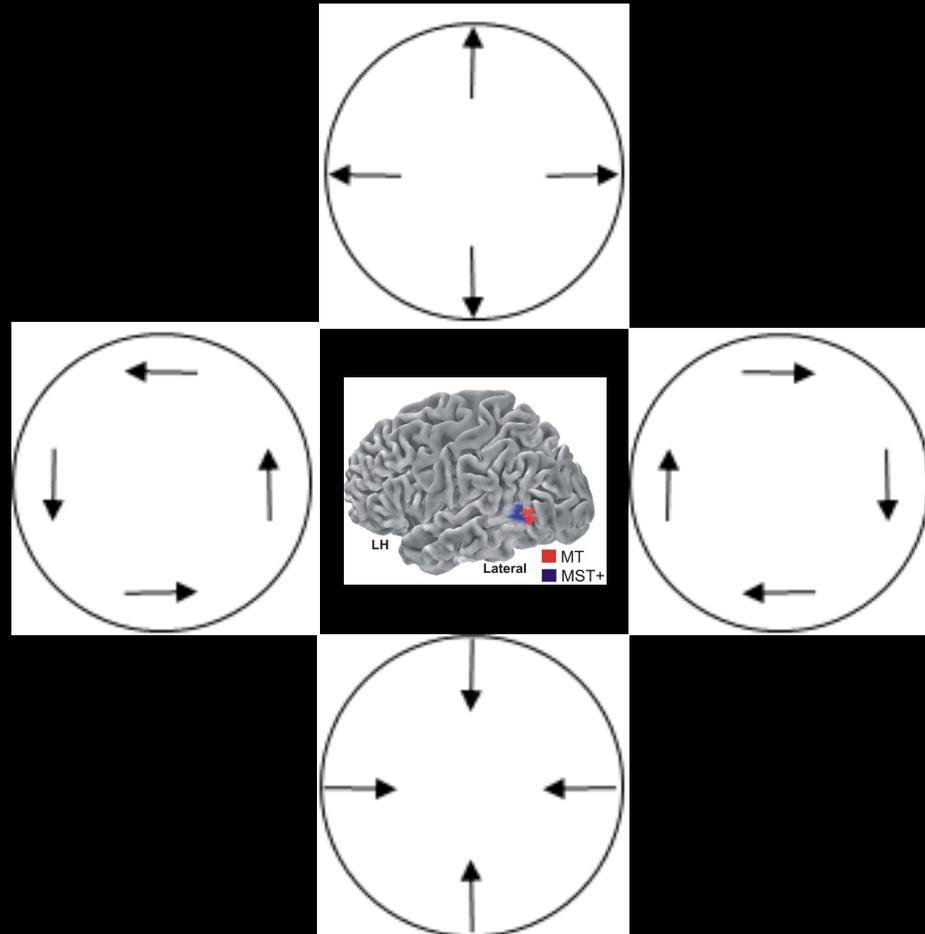
Interaction Between Motion-Type and Initial-Directions



Interaction Between Motion-Type and Initial-Directions

Group	Asynchrony	Interaction Magnitude (d')	Monte Carlo P-Value
All Groups Combined (N=121)	All Asynchronies Combined	0.8019	<0.0001
	67 Msec Asynchrony	0.8416	<0.0001
	133 Msec Asynchrony	0.8788	<0.0001
	200 Msec Asynchrony	1.214	<0.0001
Percussion (N=25)	All Asynchronies Combined	0.8676	0.0005
	67 Msec Asynchrony	1.078	<0.0001
	133 Msec Asynchrony	0.825	0.0001
	200 Msec Asynchrony	0.4851	0.0019
Brass (N=67)	All Asynchronies Combined	0.7821	<0.0001
	67 Msec Asynchrony	0.6469	<0.0001
	133 Msec Asynchrony	0.8937	<0.0001
	200 Msec Asynchrony	1.1193	<0.0001
Color Guard (N=29)	All Asynchronies Combined	0.7999	<0.0001
	67 Msec Asynchrony	0.4176	0.0245
	133 Msec Asynchrony	0.7701	0.0006
	200 Msec Asynchrony	0.8579	0.0008

Linearly Decomposing Radial & Rotational Motion

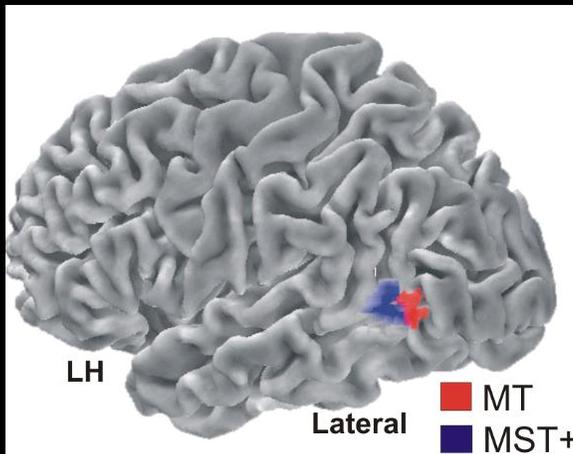


Tanaka & Saito (1989).
Duffy & Wurtz (1991a).
Duffy & Wurtz (1991b).
Wall et al. (2008).
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Pitzalis et al. (2013).

Koenderink & van Doorn (1976).
Freeman & Harris (1992).
Clifford et al. (1999).
Barraza & Grzywacz (2002).
Barraza & Grzywacz (2005).
Wurfel et al. (2005).

Visual Motion Implications

- **Dissociation between neural mechanisms of radial & rotational motion**
 - Matthews et al., 2017, Journal of Vision
 - Strong et al., 2017, Cerebral Cortex
- **Looming targets capture attention more than receding targets do**
 - Franconeri & Simons, 2003, Perception & Psychophysics



Pitzalis et al., 2013, PLoS, Figure 4

Group Differences in Reaction Time

$$p = 1 / 6^7 * 1 / 6^7 * 1 / 6^7 * 1 / 6^7$$

$$p = 1 / 6^{28}$$

$$p < 1.7 \times 10^{-22}$$

For context, this p value is less than dividing 1 by the estimated # of

Seconds Since the Big Bang: 4.35×10^{17}

<https://www.google.com/search?q=how+many+seconds+since+the+big+bang&oq=how+many&aqs=chrome.0.69i59l3j69i60j69i57j0.1255j0j7&sourceid=chrome&ie=UTF-8>

Sand Grains on Earth: 7.5×10^{18}

<https://www.google.com/search?q=how+many+sand+grains+on+earth&oq=how+many+sand+grains&aqs=chrome.0.0j69i57j0l4.7936j0j8&sourceid=chrome&ie=UTF-8>

Stars in the Universe: 1×10^{21}

<https://www.google.com/search?q=number+of+stars+in+the+universe&ie=utf-8&oe=utf-8&client=firefox-b-1>

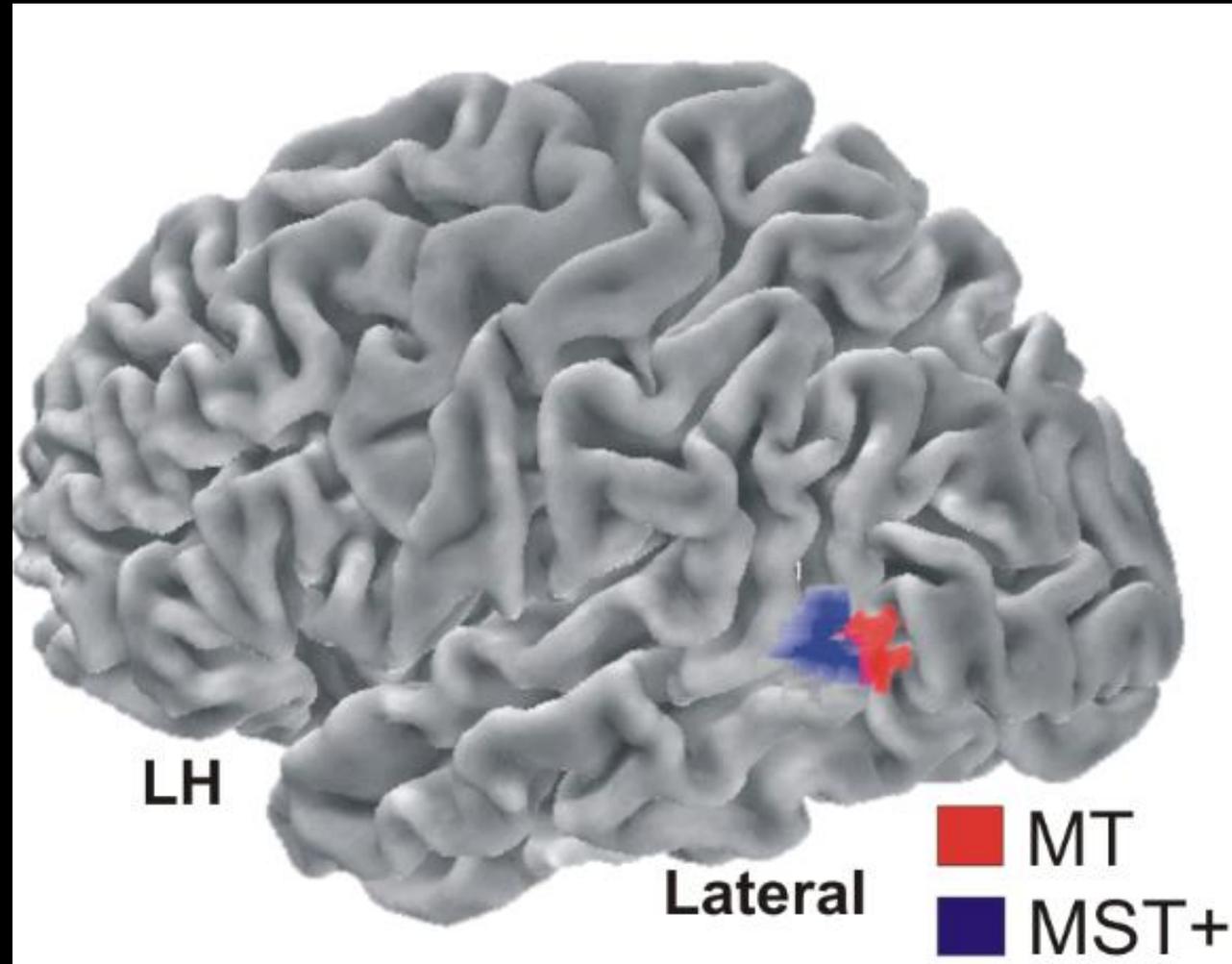
Group *Similarities* Summary

- **Reaction Time**
 - All groups responded slower at 0 msec asynchronies (stimulus control)
 - **Decision-related:**
 - Greatest TOJ uncertainty (no information) for simultaneous stimuli
- **Self-Reported dislike for the Radial-Opposite condition**
 - Multiple members of each group spontaneously stated / gestured...
“I hate the stimuli that go in and out”
Left and right hands moving in counter-phase depth
- **Significant 2x2 (Motion-Type by Initial Directions) Interaction d' ...**

About The Bluecoats

- Drum Corps International (DCI) 2016 World Champions
- 18-21 year-old artists from around fly to 1 of 4 audition sites in Dec / Jan
- Approximately 10% are accepted
 - Tuition is approximately \$3,000
- The DCI competition season - late June to early August
 - Season opening and championship in Lucas Oil Stadium, Indianapolis IN
 - Corps travel more than 10,000 miles by bus to do several shows per week
 - Members sleep on the bus or on inflatable mattresses on HS gymnasium floors

Brain Area MST (Medial Superior Temporal)



About The Bluecoats

- Five-week **spring training at Denison University** ran from May 19th to June 22nd 2017
- Each member ate 4 meals a day → **7,000 calories per day**
 - Meals prepared by rotating shifts of volunteer parents
- Rehearsals ran **7 days a week, 13 hours a day** (Wednesday night's "off")
 - 7 AM – Rise
 - 8 AM – **Collective Breakfast**
 - 9 AM – Training on the Field / Sectionals / Physical Training
 - 1 PM – **Collective Lunch**
 - 2 PM – Training on the Field / Sectionals / Physical Training
 - 6 PM – **Collective Dinner**
 - 7 PM – Training on the Field / Sectionals / Physical Training
 - 10 PM – **Collective Dinner #2....or My Psychophysical Experiment**
 - 11 PM – Dormitory Curfew

Group-Differences Implications

- **Despite sharing...**
 - Rigorous auditions (10% acceptance rate)
 - Rigorous rehearsal schedules (13-hour days; 7,000 calories)
 - A 10 – 11 PM psychophysical test *after a 13-hour rehearsal day*
 - A DCI show *precisely synchronized across groups at 180 BPM...*
- **Despite**
 - Color guard's experience with precisely timed rotational and radial motion
 - which is VISUAL experience
 - Percussion & Brass emphasis on AUDITORY versus visual experience...