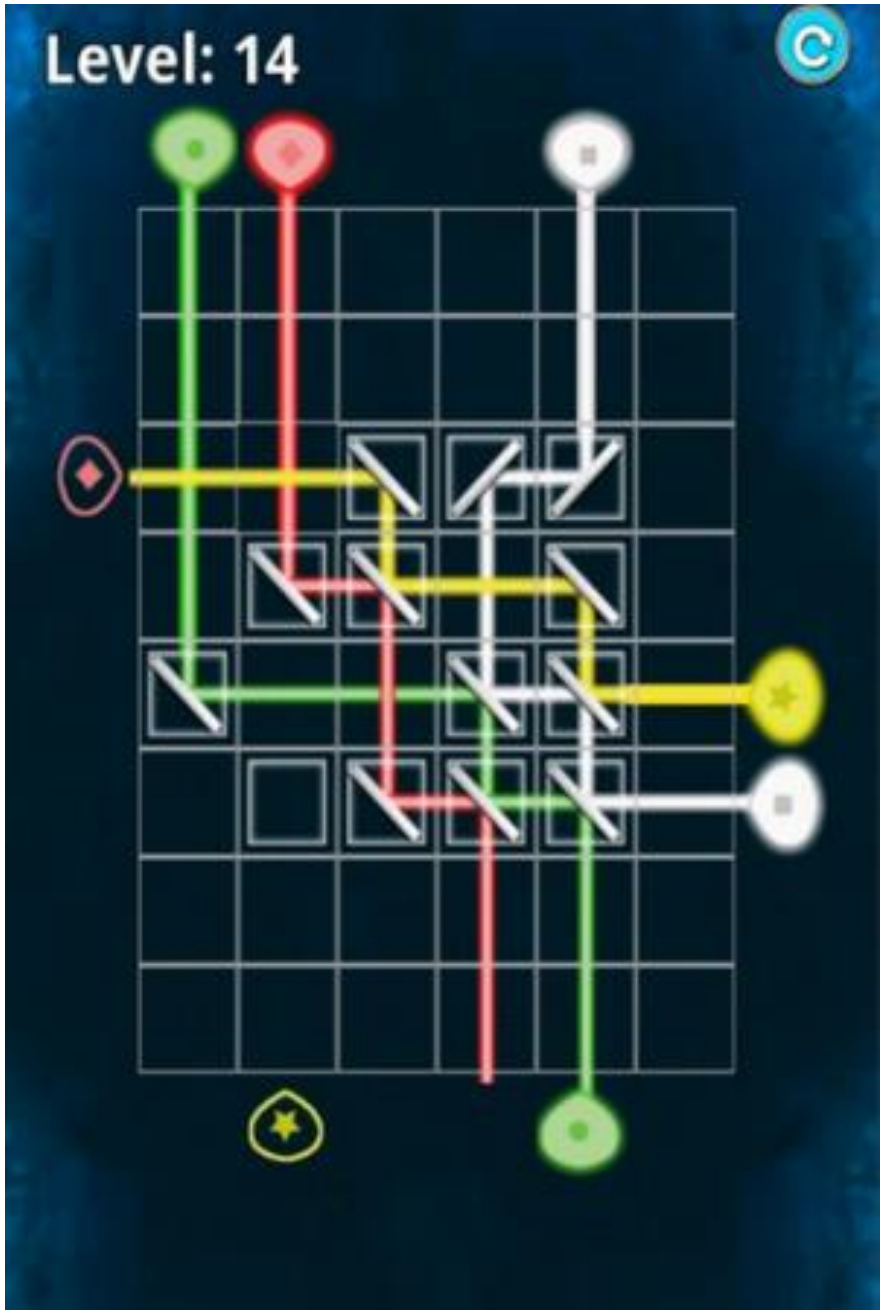
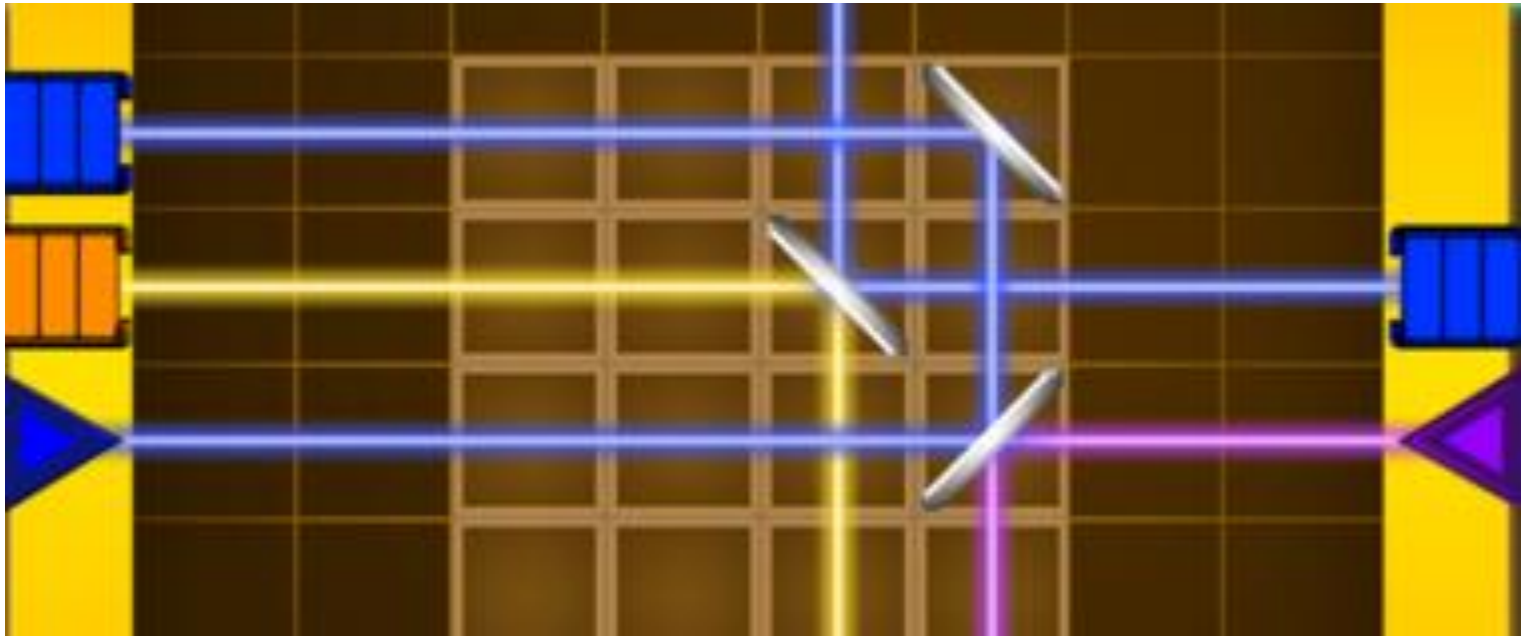
The most beautiful campus that ever there was.
-Robert Frost

MIAMI UNIVERSITY
ORIGINAL PUBLIC IVY
OXFORD, OHIO • EST. 1809

$4^{o}C$





Children Ages 6-12 Learning Optical Spatial Reasoning during Educational Video Game Play: An ERP study examining the role of cognitive load.

Joseph E. Schroer

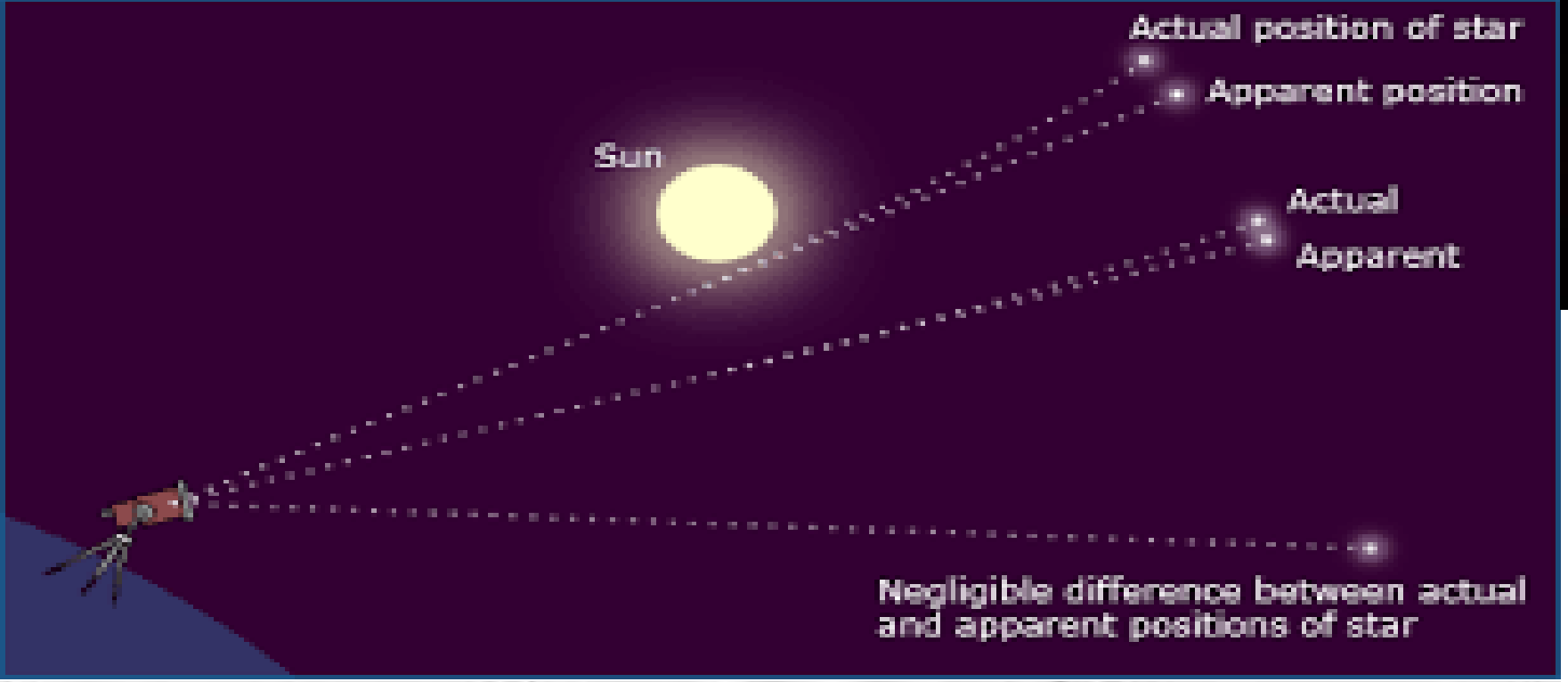
Miami University Ohio, USA

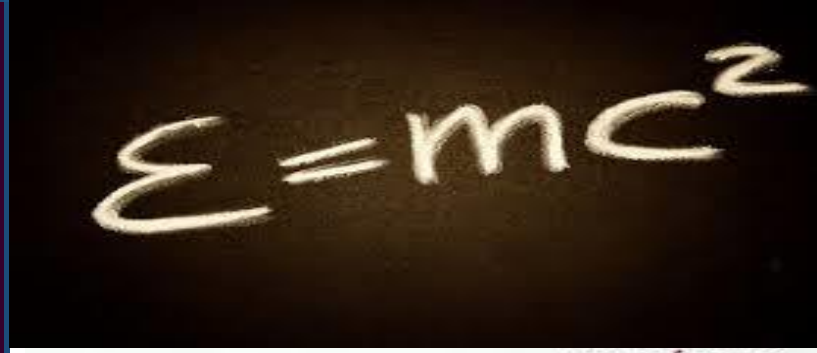
Department of Educational Psychology

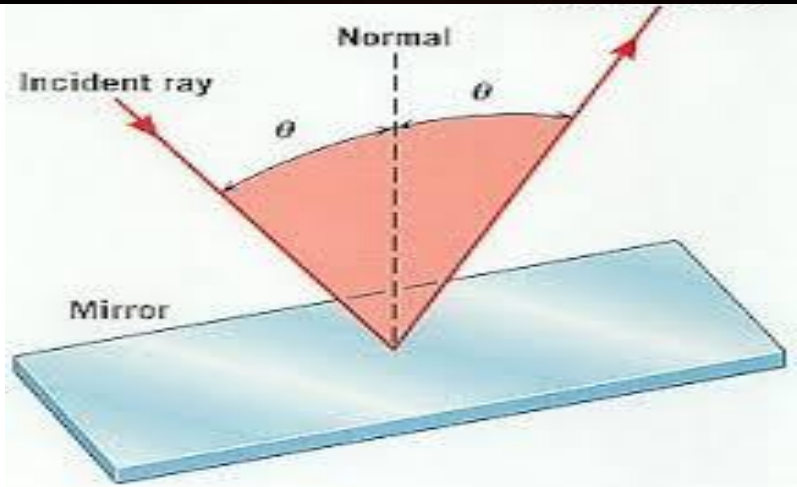
Optical Spatial Reasoning

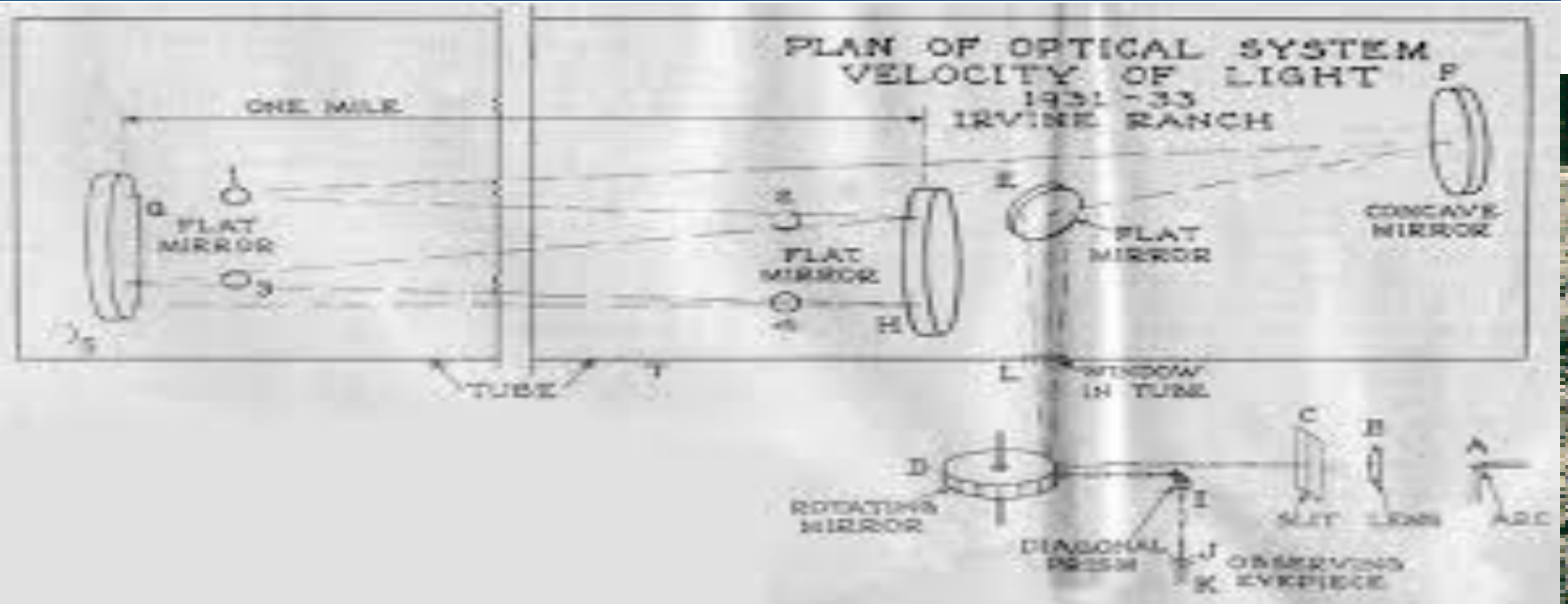
Or Naïve Optics

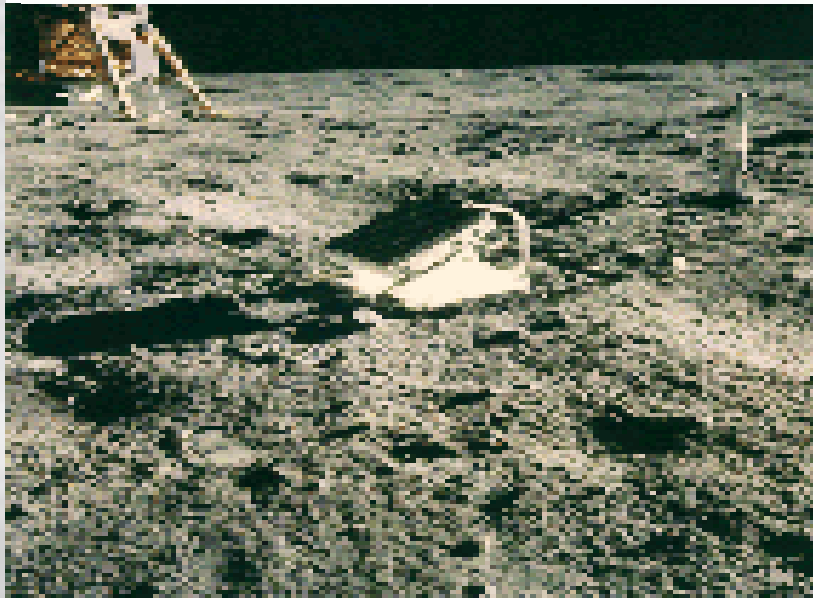
A subcomponent of spatial visualization


Actual position of star
Apparent position
Sun
Actual
Apparent
Negligible difference between actual and apparent positions of star


$E = mc^2$

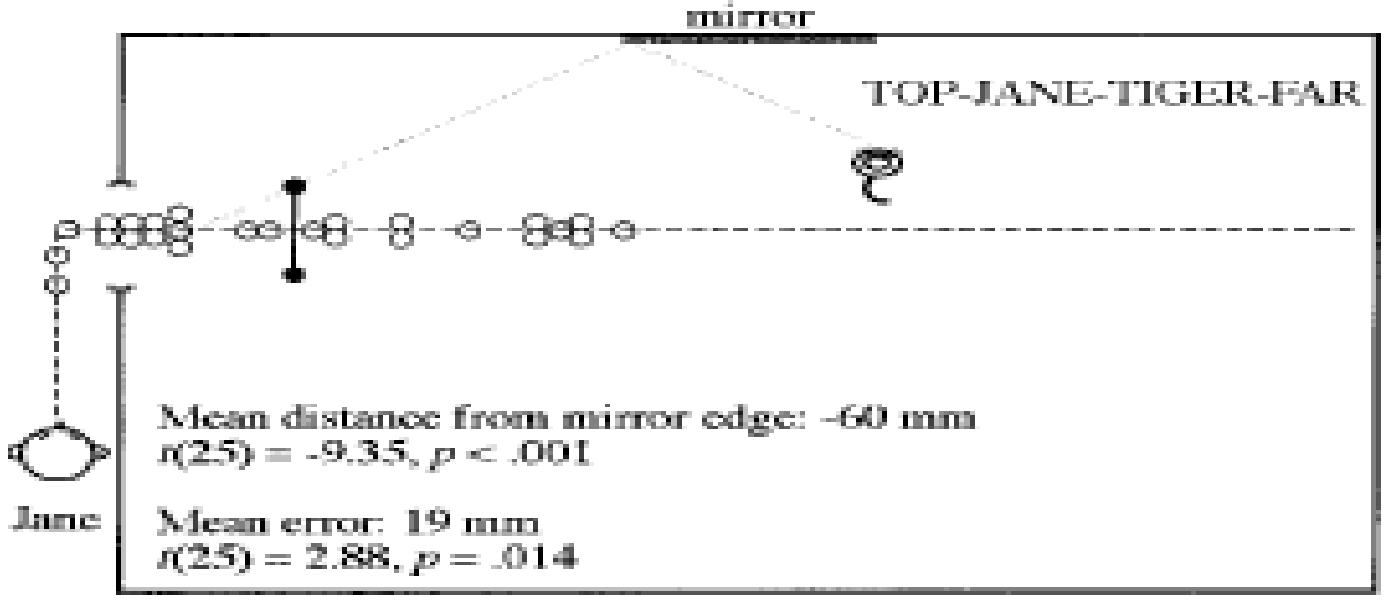

Normal
Incident ray
θ
θ
Mirror


PLAN OF OPTICAL SYSTEM
VELOCITY OF LIGHT
1931-33
IRVINE RANCH
ONE MILE
FLAT MIRROR
FLAT MIRROR
FLAT MIRROR
CONCAVE MIRROR
TUBE
WINDOW IN TUBE
ROTATING MIRROR
SLIT
LENS
OBSERVING EYEPIECE



Spatial Reasoning & Naïve Optics

- Croucher, Bertamini, and Hecht (2002)
  - physically draw equal angles when asked about a ray of light reflected by a mirror
  - erroneously apply naïve theories or heuristics when encountering images depicting the use of mirrors in the horizontal plane
  - Hypothesis: people rotate mirrors toward a specific vantage point of an observer

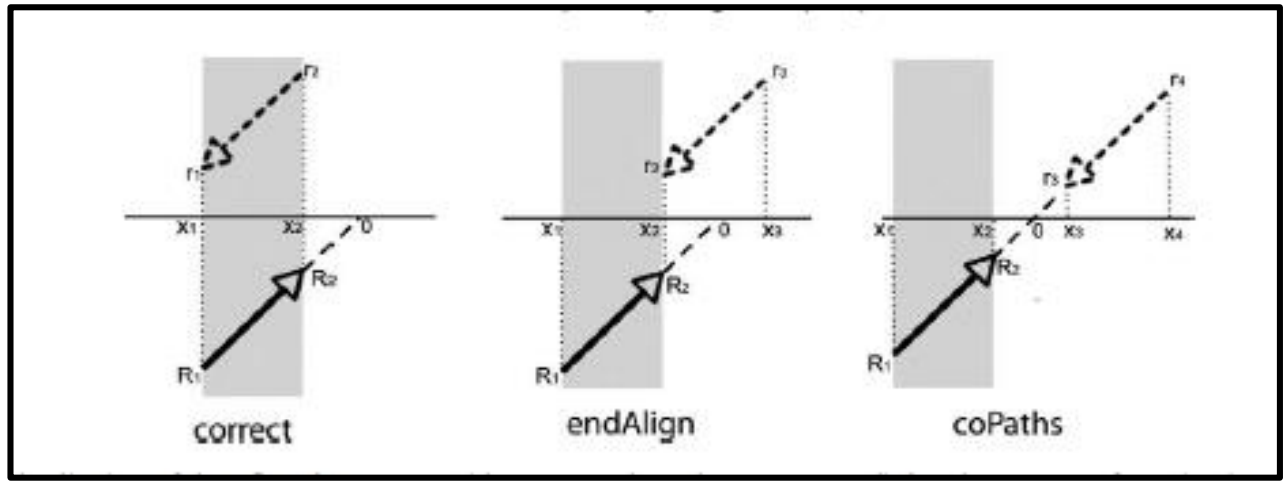


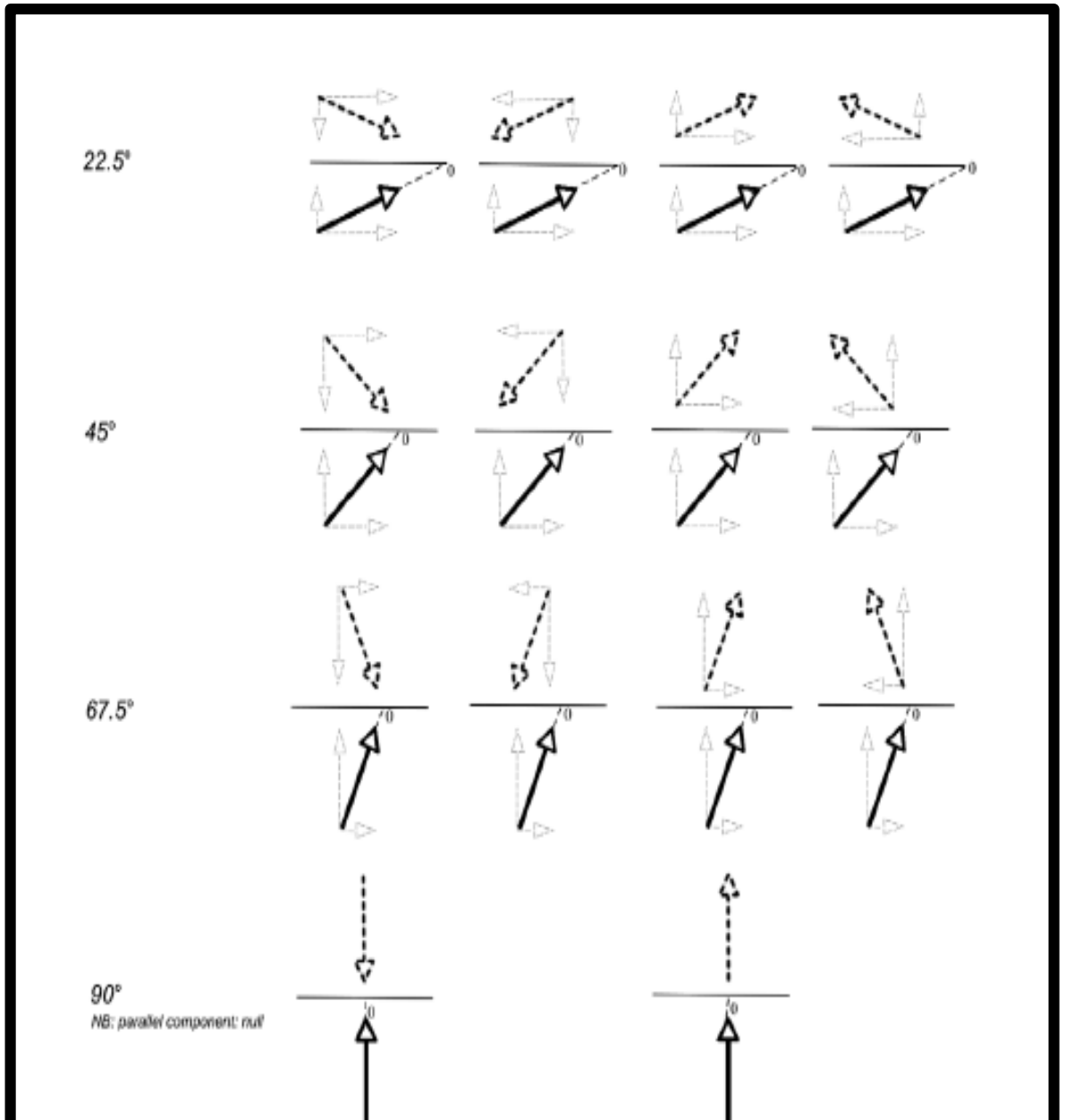
Jane walks through the door and across the room, please mark the point at which she can first see the cat in the mirror.

Spatial Reasoning & Naïve Optics

Savardi, Bianchi, and Bertamini (2010)

- individuals' predictions of both dynamic and static mirror reflections
- people make either perceptual errors that can be corrected through visual feedback, or conceptual errors that cannot

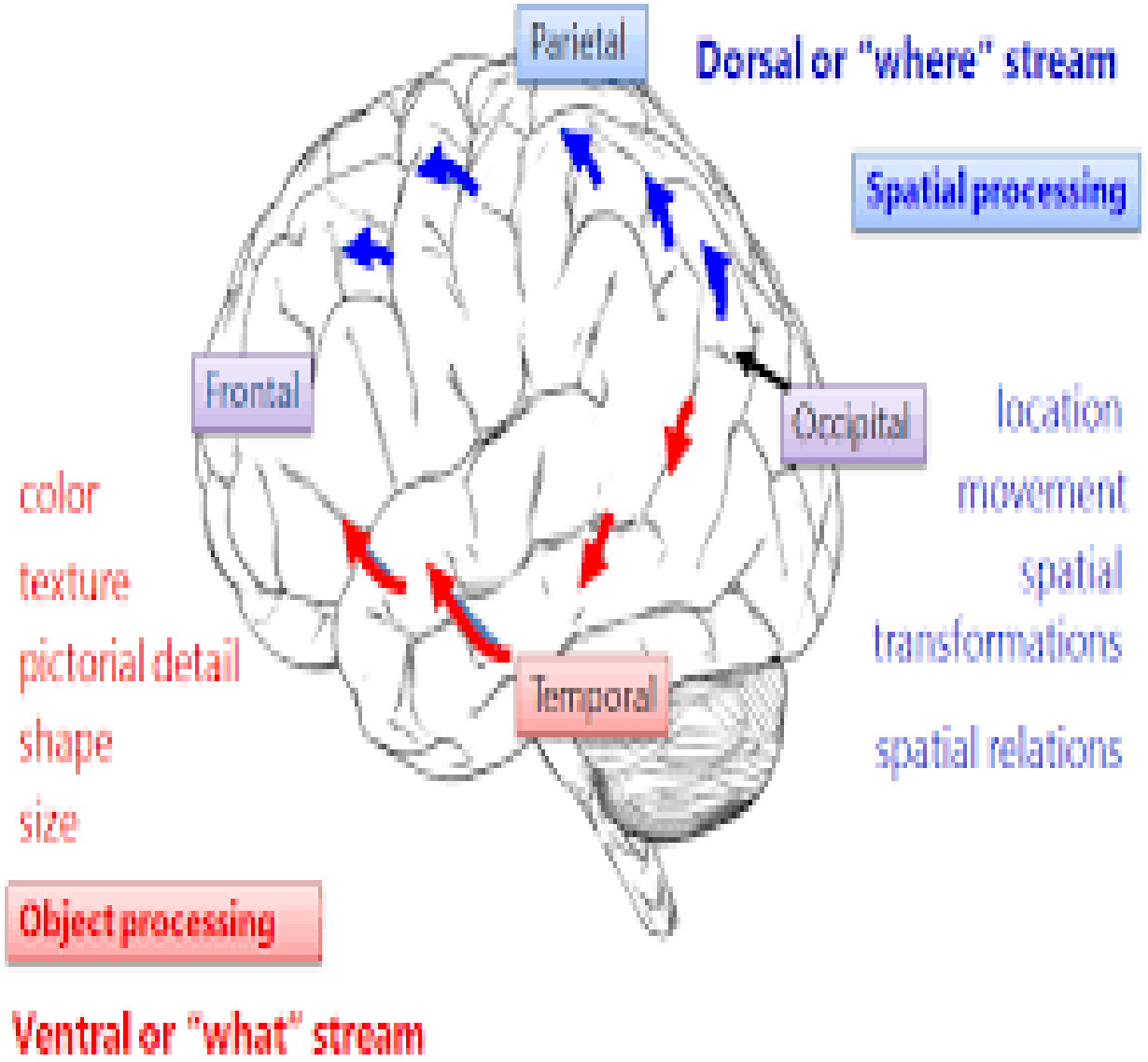


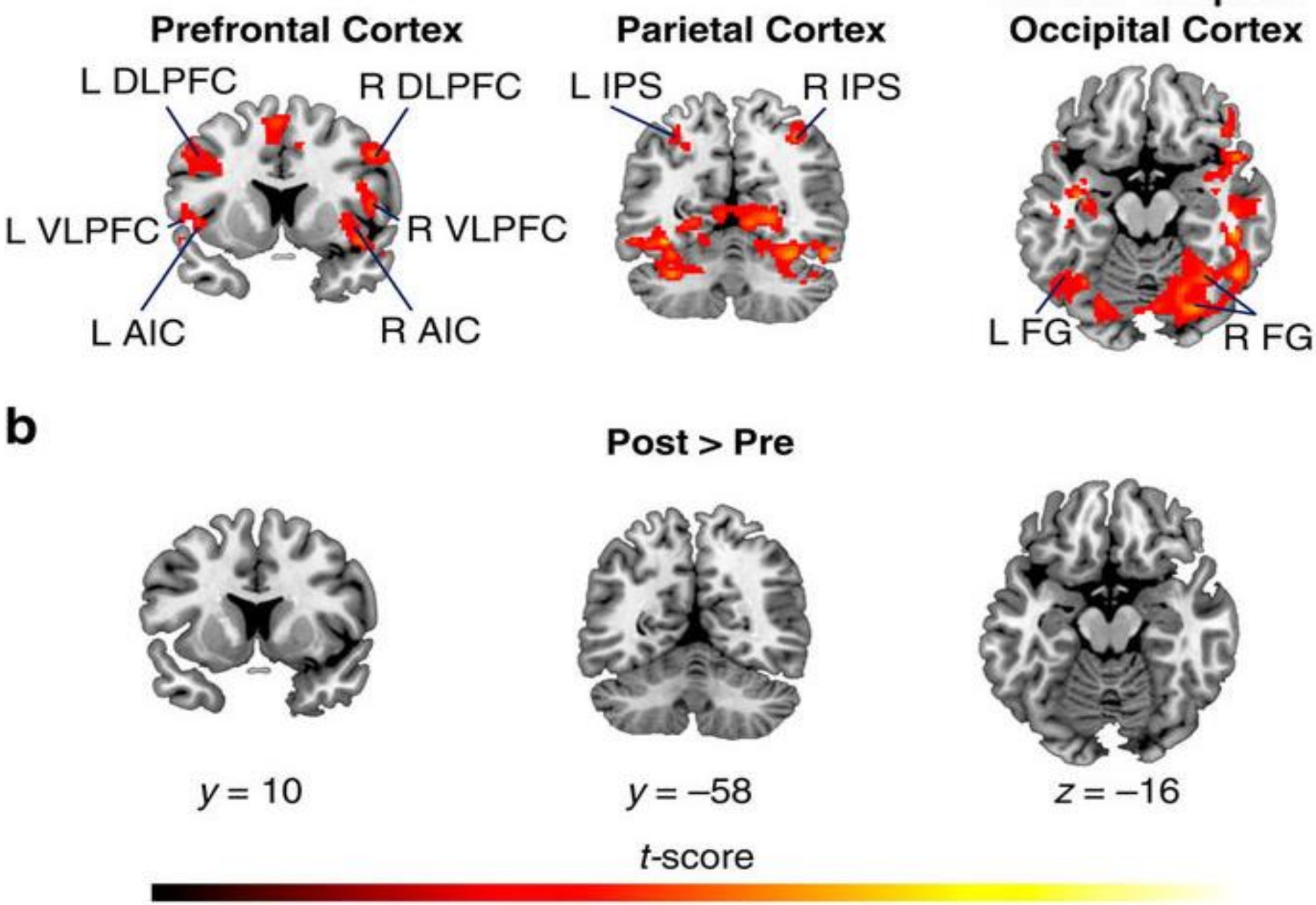


Visuospatial Working Memory

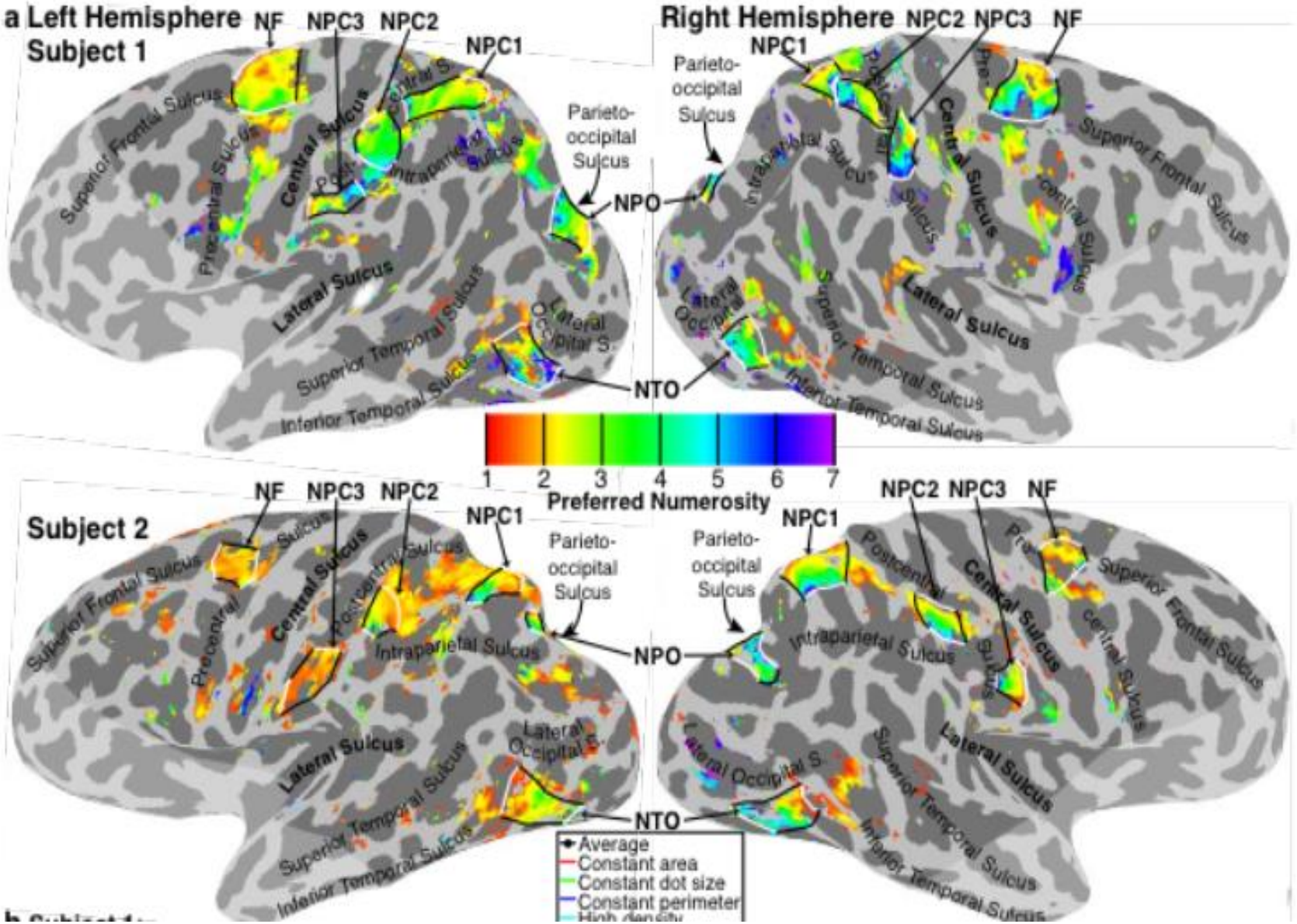
VSWM

- Macaque monkeys activate the **occipitoparietal pathway** with the dorsal limbic and dorsal frontal cortex (Mishkin et. al., 1983, p. 414)
- VSWM activates the **superior frontal sulcus** (ie., Courtney et. al., 1998)
- Dorsolateral Prefrontal Cortex (**DLPFC- spatial**) & Ventrolateral prefrontal cortex (**VLPFC-objects**) (Nakahachi et al., 2010)

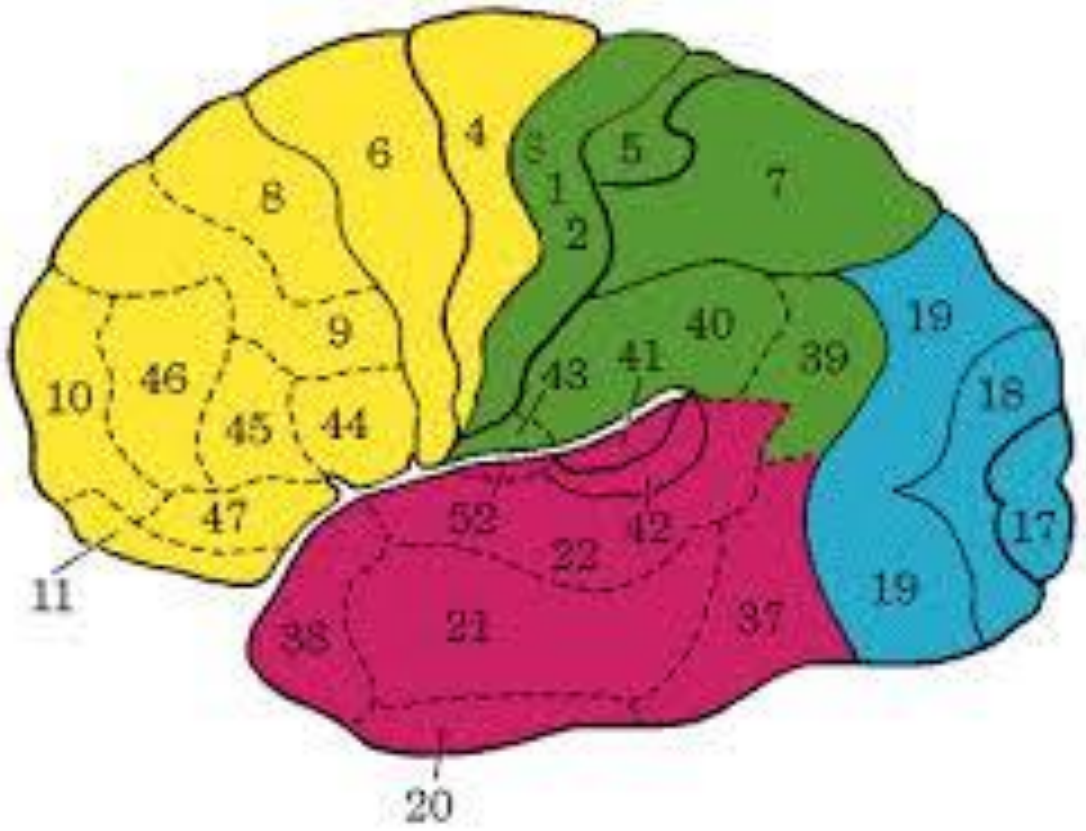


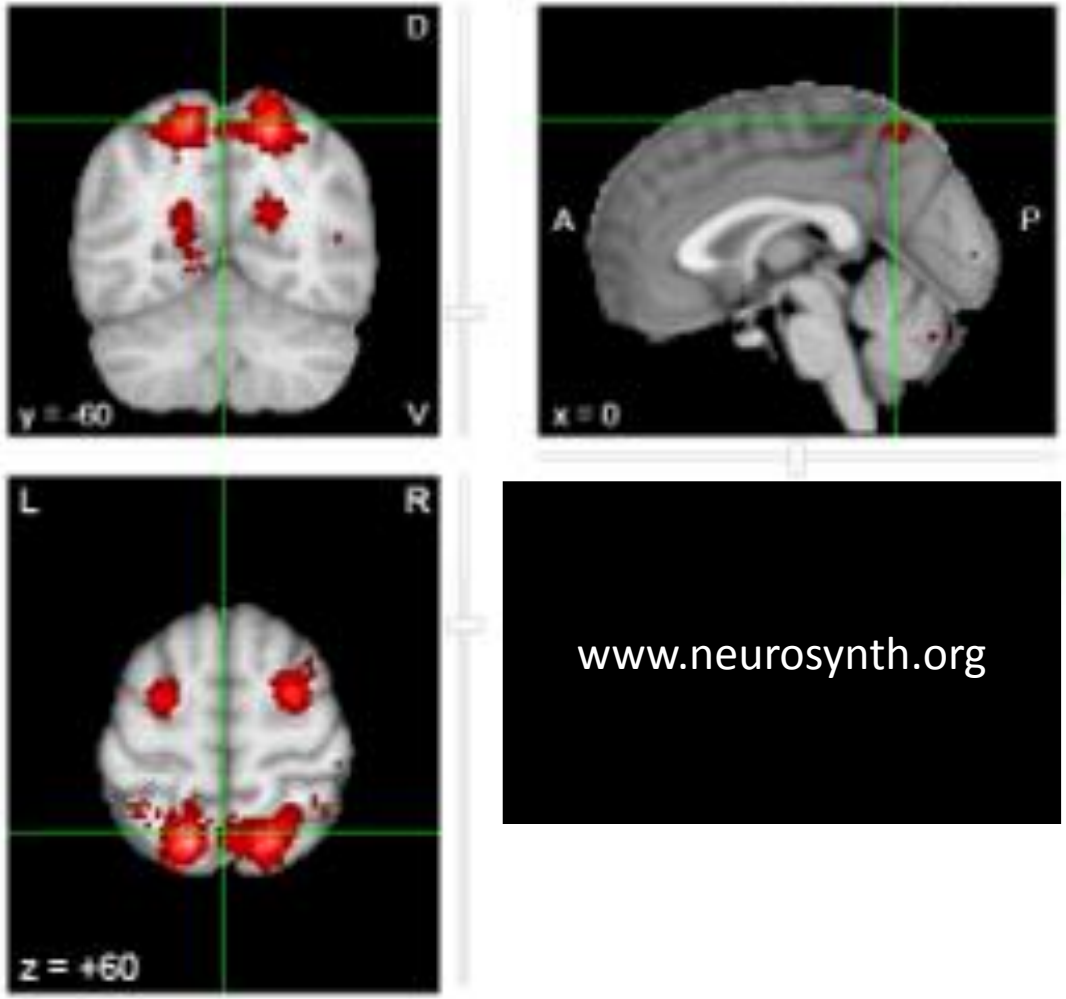


VSWM Tutoring-induced functional brain plasticity in children 7-9 with MD.
Source Iuculano et al., 2016.



A network of topographic numerosity maps in human association cortex. Harvey & Dumoulin (2016)





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Research Questions

Research Questions & Hypotheses

1. **Can children increase spatial reasoning abilities through video game play?**
   - H_1= Yes they can.
2. **Are there developmental and gender differences in behavioral performance during spatial reasoning video game play?**
   - H_1= Yes there should be with Males outperforming Females; Older children outperforming Younger.

3. What neural correlates of the brain are significantly impacted in spatial reasoning learning?

H_1= Fronto-Parietal Network

H_2= Reduced Parietal Amplitude ERPs for Increase in Number of Mirrors

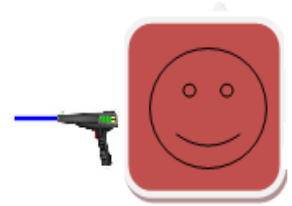
- Research points to less positive values in more mental rotation turns

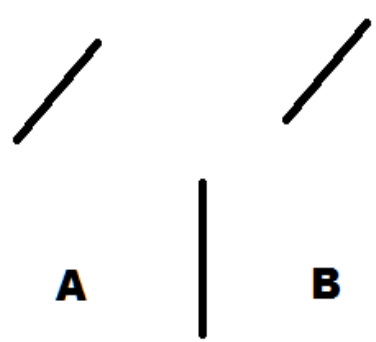
H_3=Frontal L/R differences & correlations

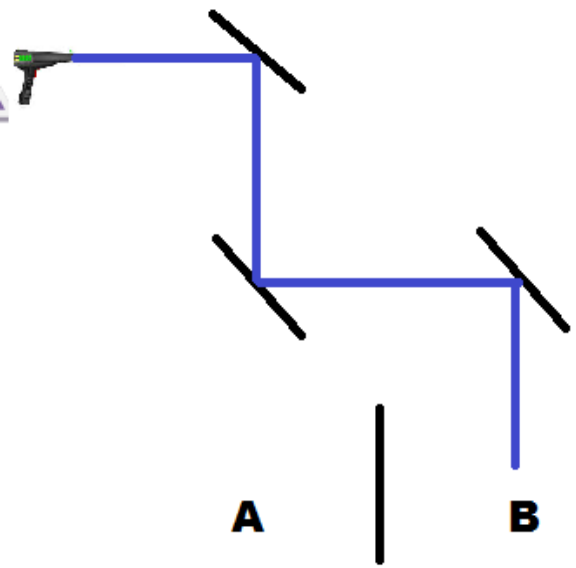
- JTF-Coherence Value Calculations

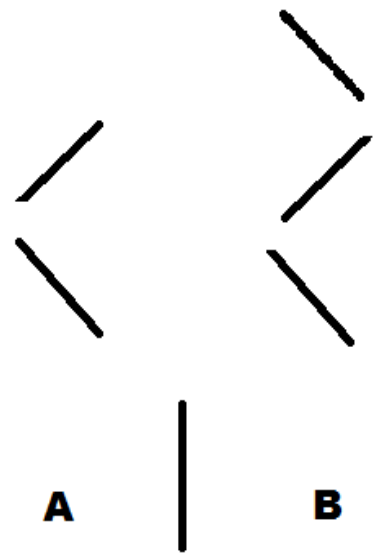
Study Design


A
B




A
B

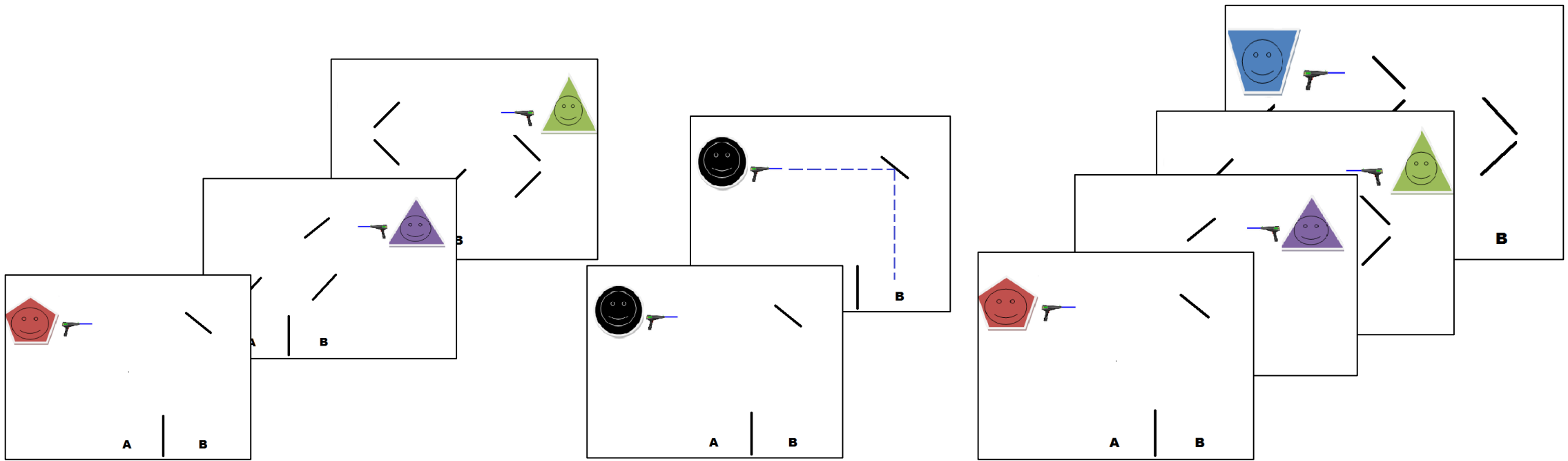

A
B

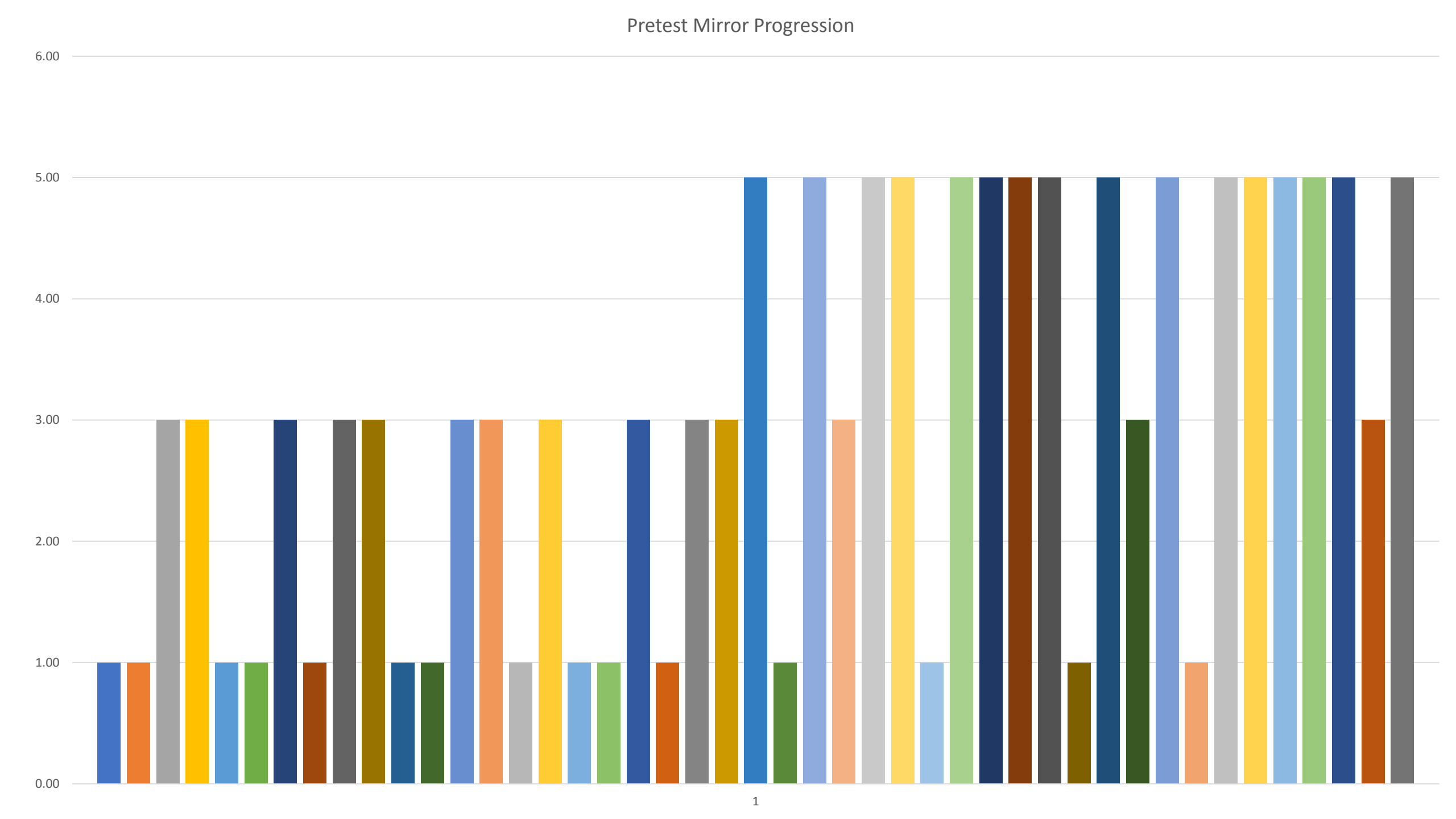

A
B

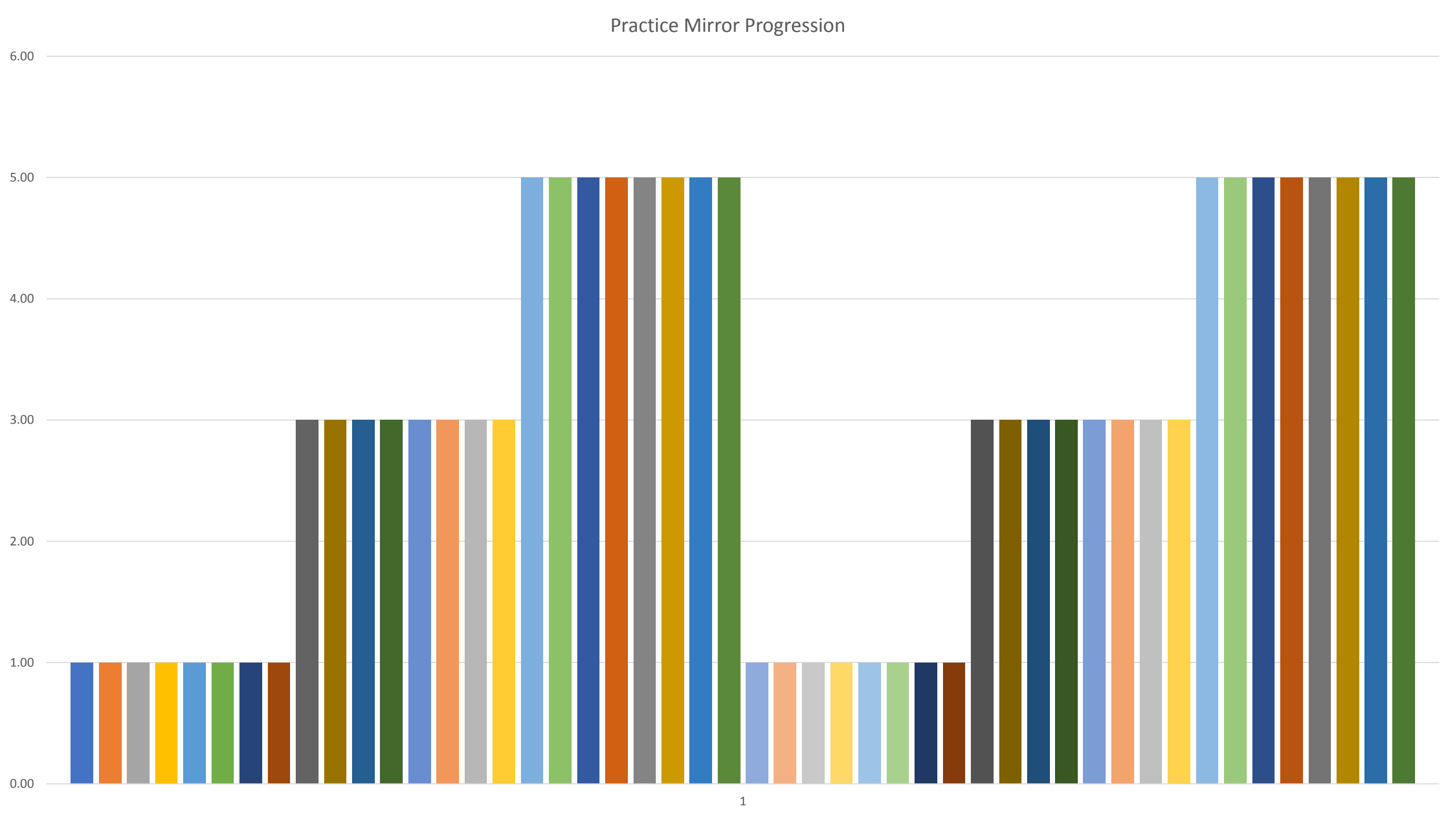
Methods

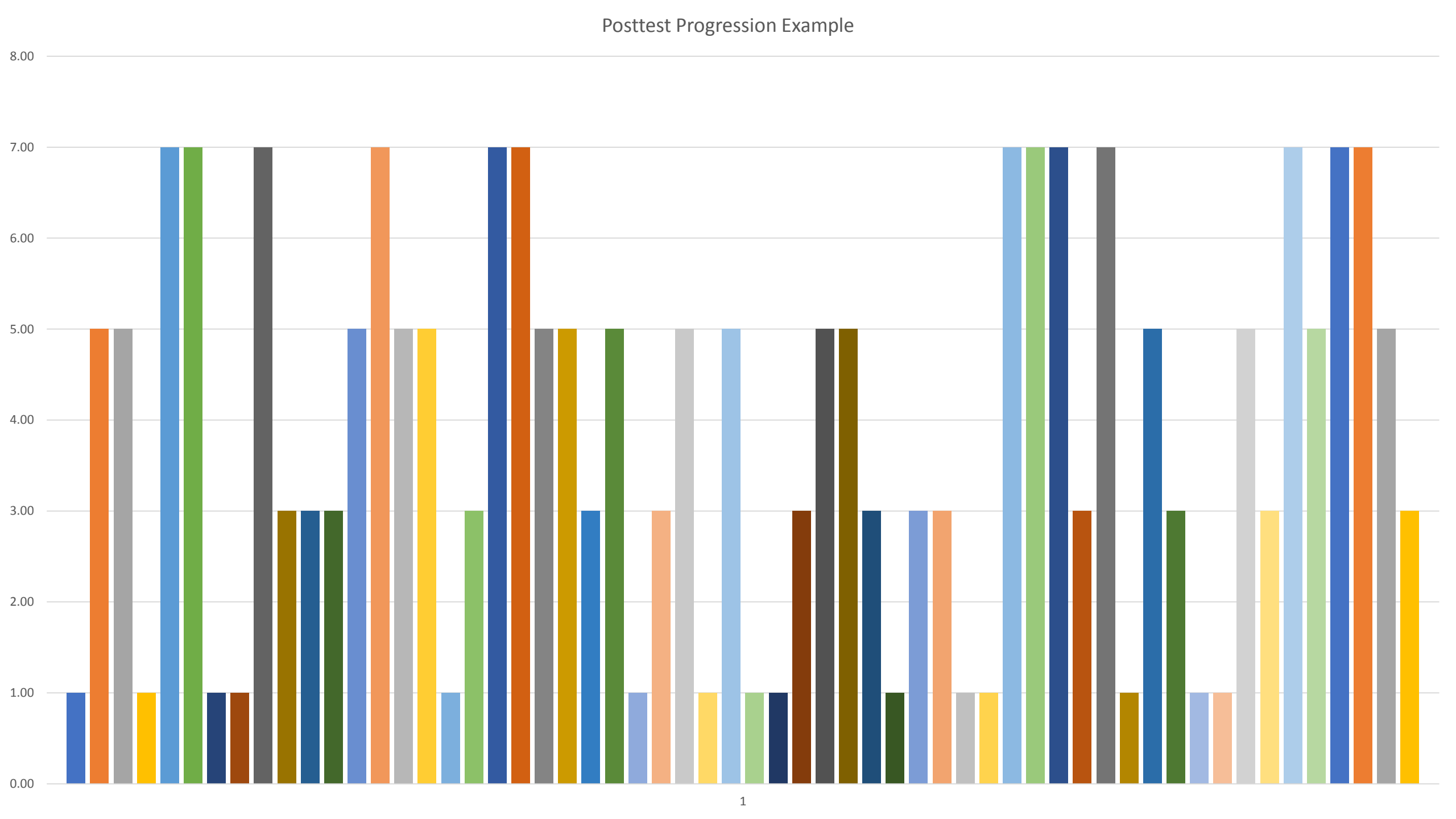
Study Design

- Conditions within the 3 blocks; pretest, practice (with feedback, see figures), and posttest blocks; 1 mirror, 3 mirror, 5 presentations (& 7 posttest)
  - three blocks totaled 152 trials, 46 trials pretest, 48 trials practice block, and 58 trials posttest block




Pretest Mirror Progression
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1


Practice Mirror Progression
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1


Posttest Progression Example
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1

Participants

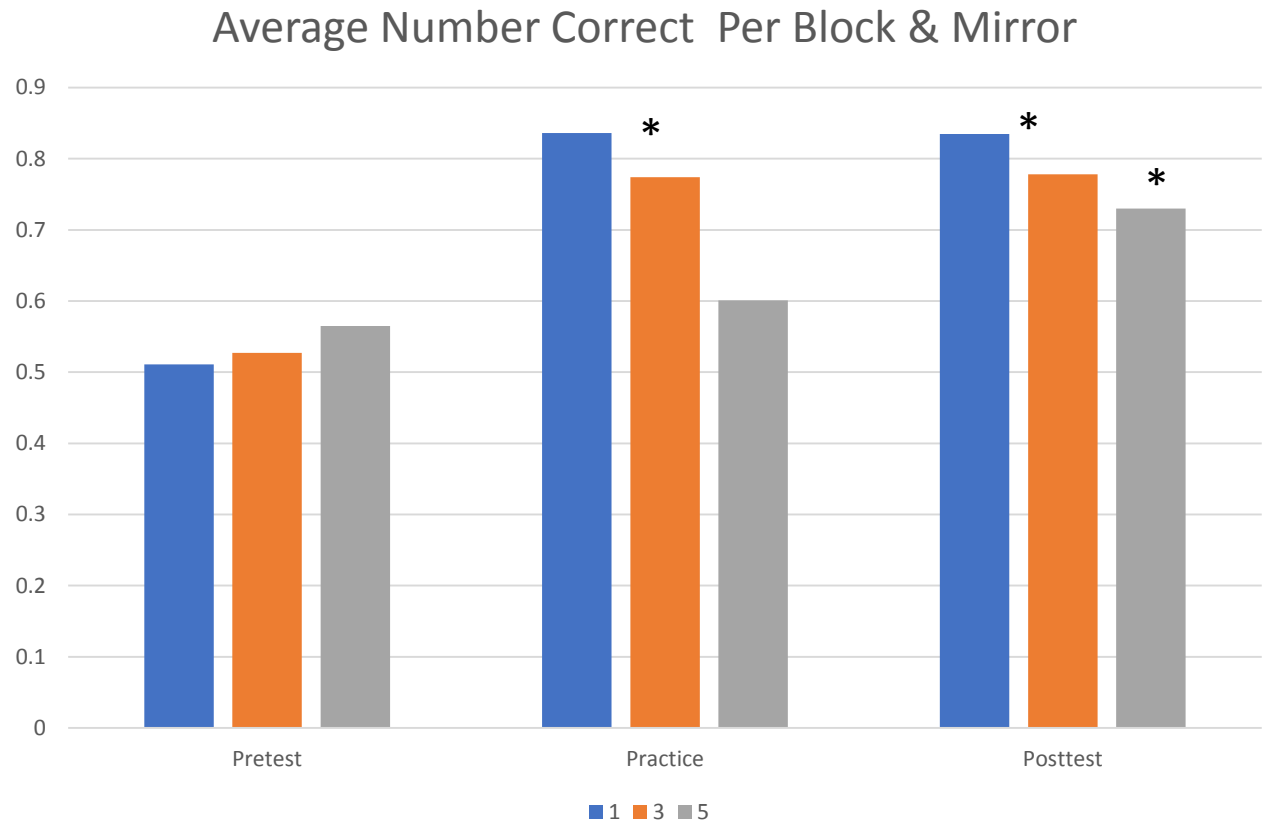
- Twenty-one (21) children ages 6 to 12; 11 boys and 10 girls
- Average Age 9.2
  - 7 children in the 6-7 Age group
  - 5 children in the 8-9 Age group
  - 9 children in the 10-12 Age group
- All Right-handed

Can children increase spatial reasoning abilities through video game play?

Q1

Results

Children **overall** performed better on the practice (F=7.97, p<.001) and the posttest (F=15.33, p<.001) than on the pretest.



Mirrors	1			3			5			7			
	N	M	SD	N	M	SD	N	M	SD	N	M	SD	F
Pre-test	315	.511	.500	284	.527	.500	336	.565	.496				1.023
Practice	336	.836	.370	336	.774	.420	336	.601	.490				27.01***
Post-test	315	.835	.371	293	.778	.416	337	.730	.444	273	.604	.490	14.91***

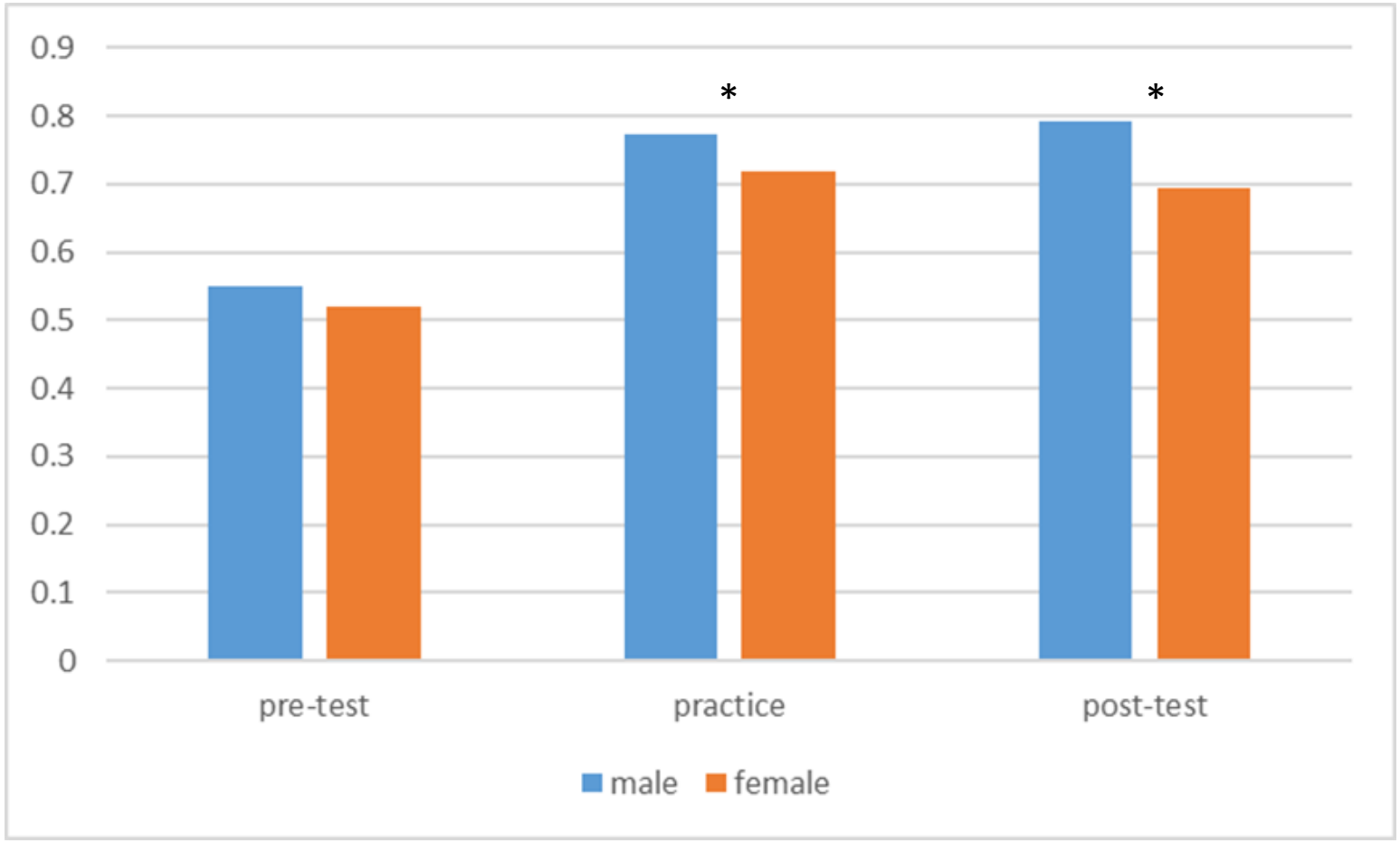
Note. * = p < .05, *** = p < .001.

Are there developmental and gender differences in behavioral performance during spatial reasoning video game play?

Q2

Behavioral Results- Gender

Figure 1. Gender comparison over three blocks



Behavioral Results- Gender

Gender （Independent samples t-test）

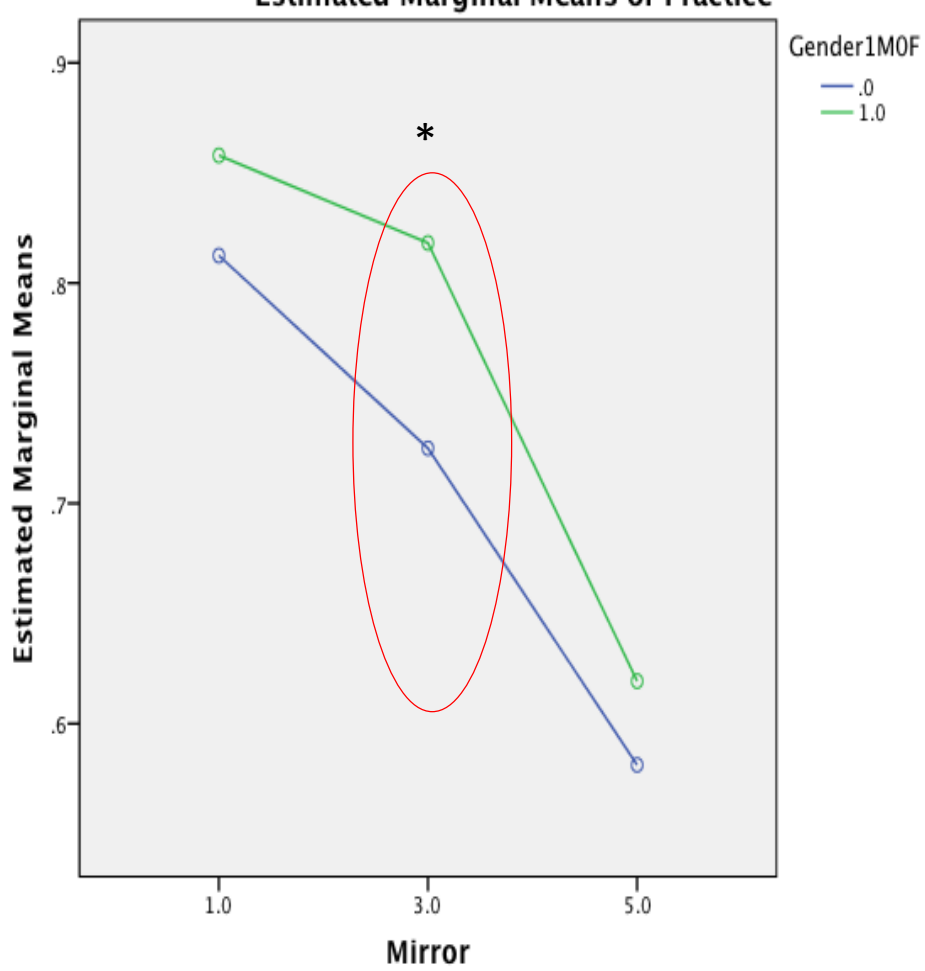
	Gender				
	Male	Female	F	t	df
Pre-test	.549	.520	2.706	-.907	943
Practice	.765	.706	17.880	-2.124***	1006
Post-test	.782	.695	48.084	-3.486***	1216

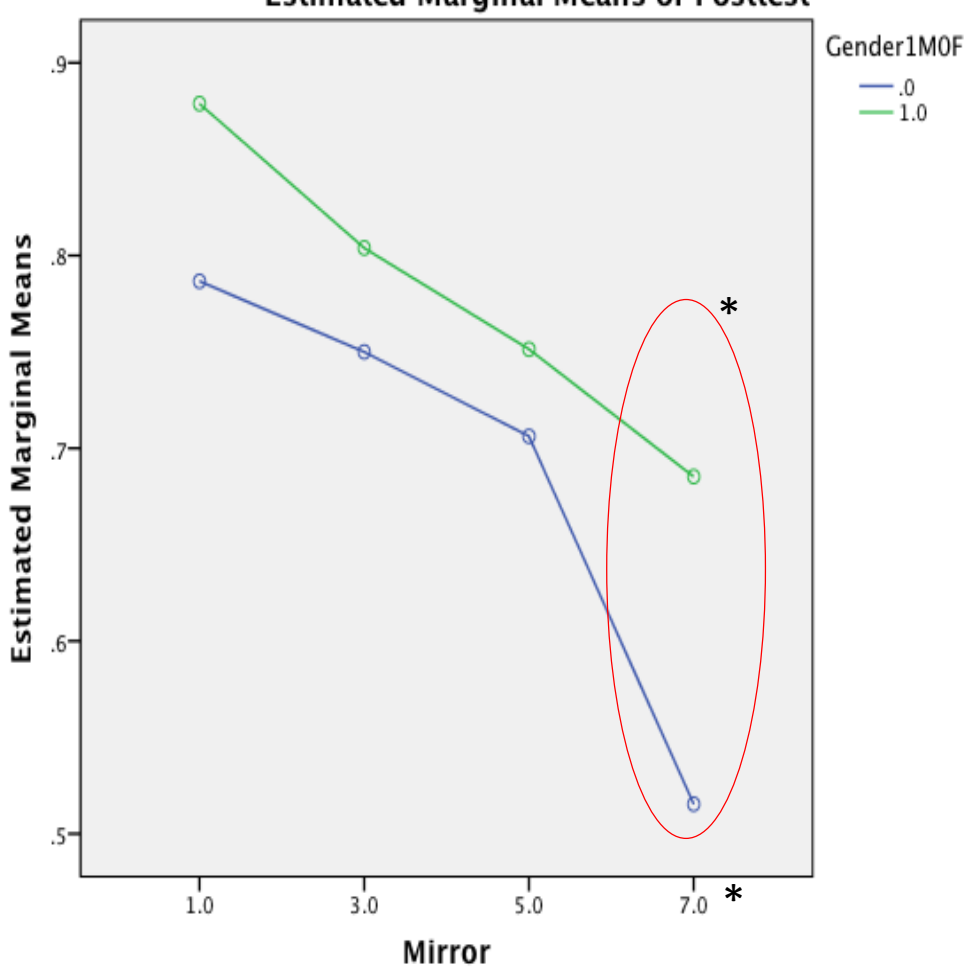
Note. * = p < .05, *** = p < .001.

Table 2. Three blocks' means for males and females

test (F=48.08, p=.000）

No significant difference between males and females in the pre-test (F= 2.706, p=.100).





- **Both genders performed better.**
- **Males performed significantly better on Practice and Posttest for select mirrors**

Results

Development (ANOVA)

- No significant differences between developmental levels in the pretest (F=.292, p=.589)
- Significant differences in developmental levels during the practice (F=14.72, p<.001) and the posttest (F=13.25; p<.001) blocks.

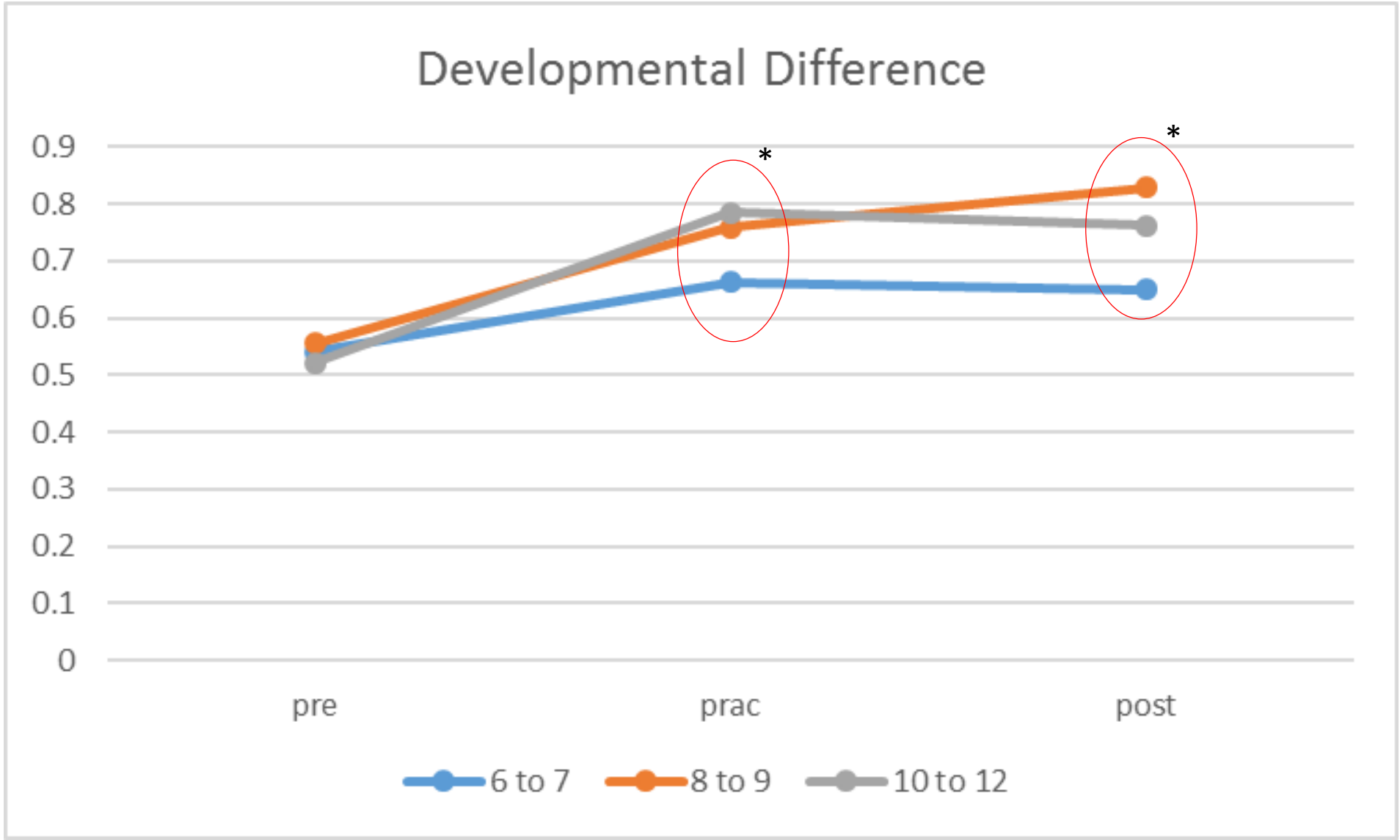
Table 2 *Developmental comparison results*

Development Age Level	6-7			8-9			10-12				
	N	M	SD	N	M	SD	N	M	SD	F	η2
Pre-test	7	.540	.50	5	.556	.50	9	.521	.50	. 364	
Practice	7	.662	.47	5	.758	.42	9	.785	.41	7.966***	.13
Post-test	7	.650	.48	5	.828	.38	9	.762	.42	15.325***	.16

Note. * = p < .05, *** = p < .001.

Results

Figure 2. Developmental comparison over three blocks



Behavioral Results-Reaction Time

ANOVA (Developmental Level)

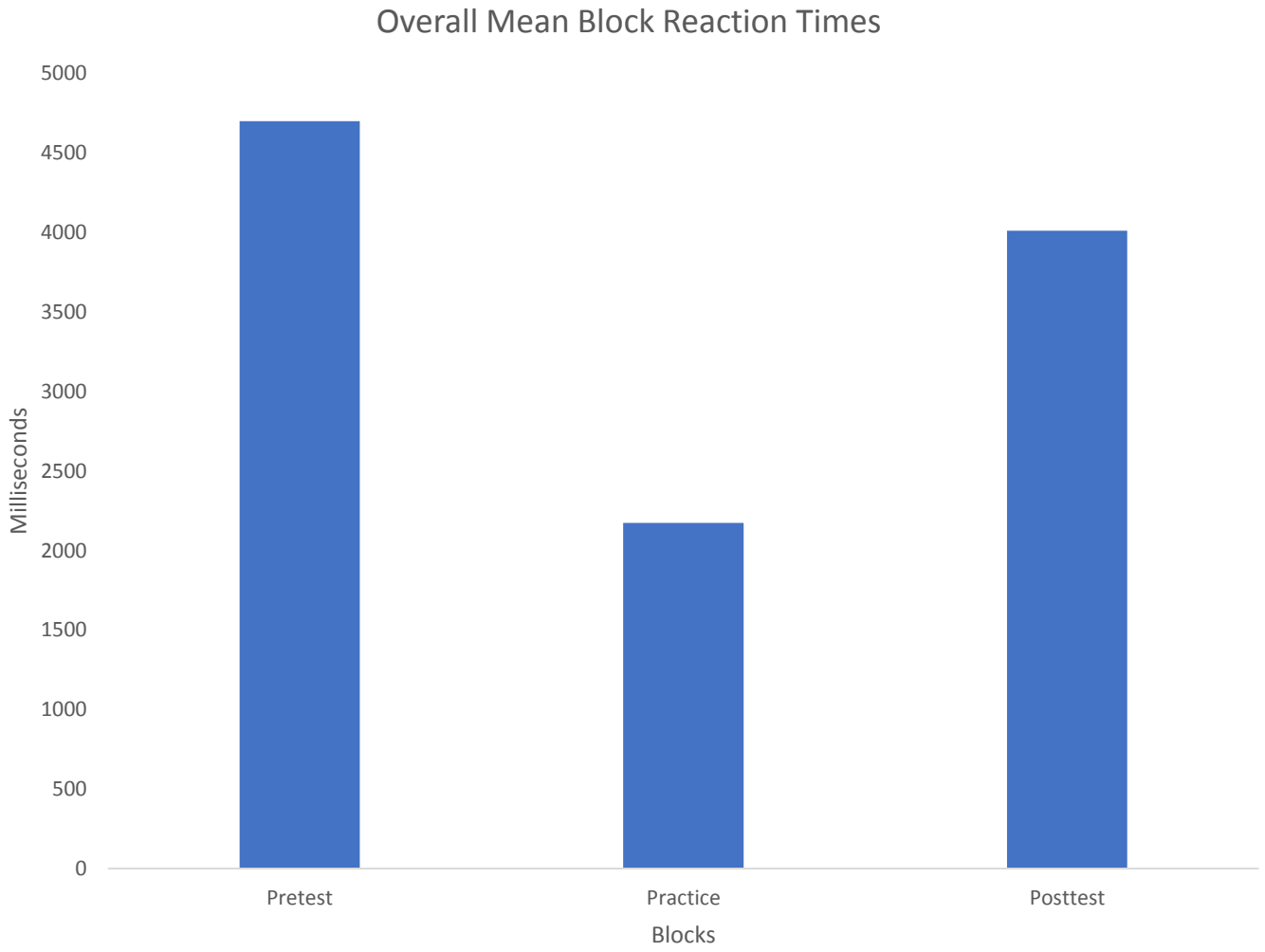
- Significant differences were found in all three Blocks: Pretest $F(1,942)=37.44$, $p<.001$, Practice $F(1,1005)=12.24$, $p<.001$, Posttest $F(2, 1215)=5.98$, $p=.003$.
- Posthoc results for Development (Scheffe)
  - Significant differences between in Pre: 6-7 and 8-9, and 10-12
  - Significant differences between in Prac: 6-7 and 8-9, and 10-12
  - Significant differences between in Post: 8-9 and 10-12**

****10-12 year-olds much faster 1,000ms**

Behavioral Results-Reaction Time

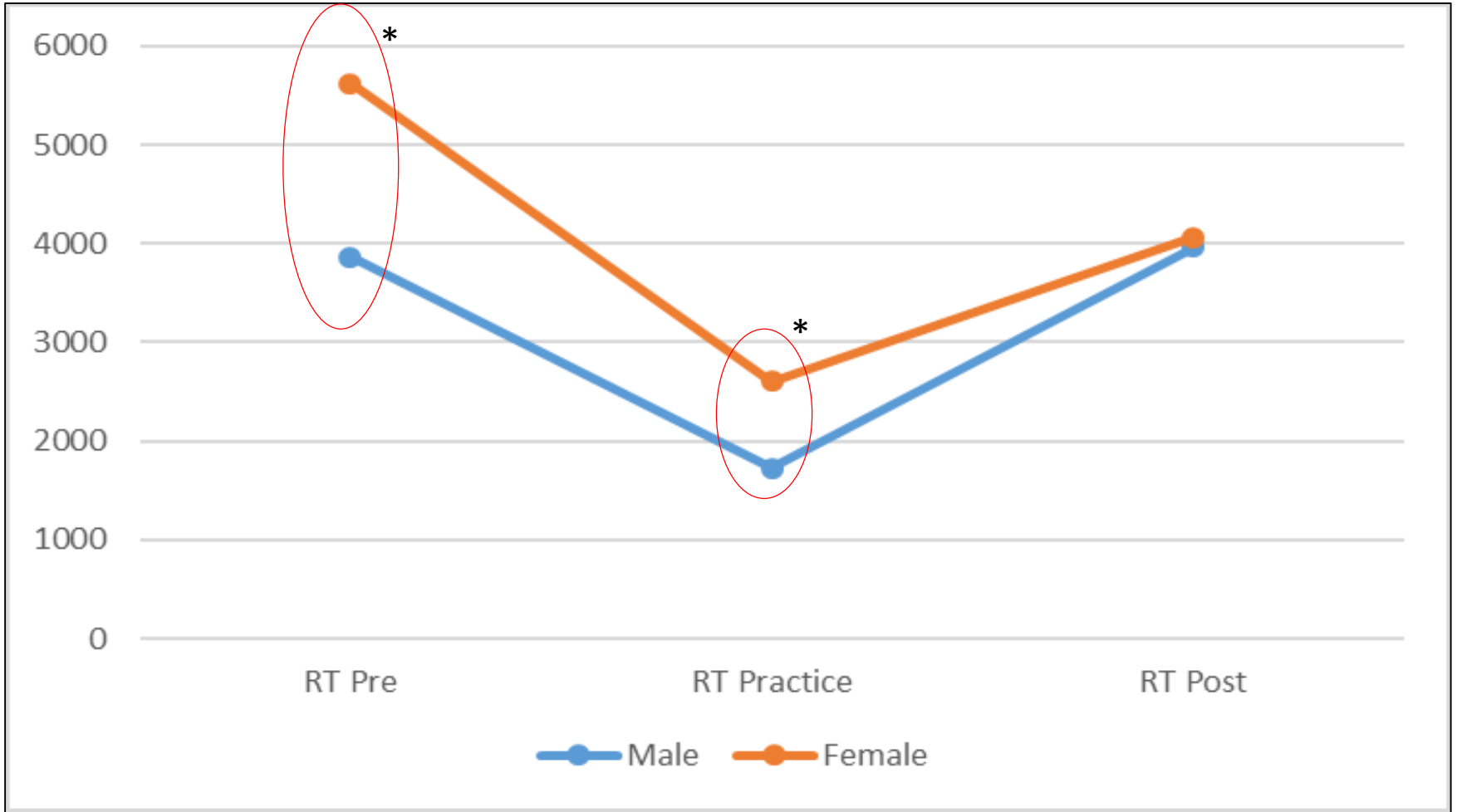
Paired sample T-tests Pre-Prac-Post

- Significant difference Pre-Prac $t(944)=11.438$, $p<.001$
- Significant difference Practice-Post $t(1007)=-11.11$, $p<.001$
- Significant difference Pre-Post $t(944)=3.01$, $P<.005$
  - Pre Mean RT = 4,700ms
  - Practice Mean RT = 2,174ms
  - Post Mean RT = 4,012ms
    - Correlation between Pre-Post $r=.09$, $p=.005$



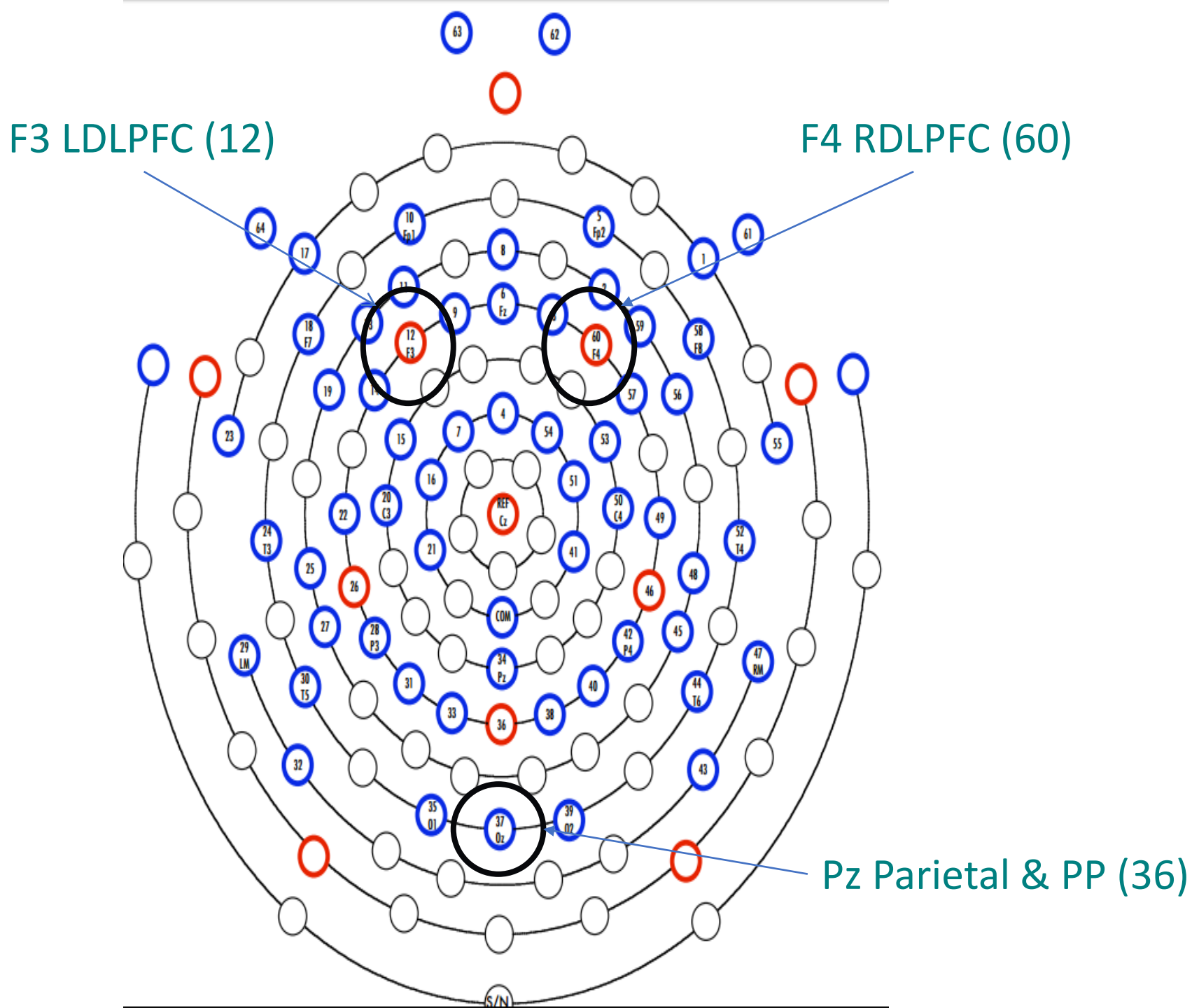
Behavioral Results-Reaction Time

- Male overall had faster reaction times on all three blocks
- Female reaction time decreased as the game progressed



What neural correlates of the brain are significantly impacted in spatial reasoning learning?

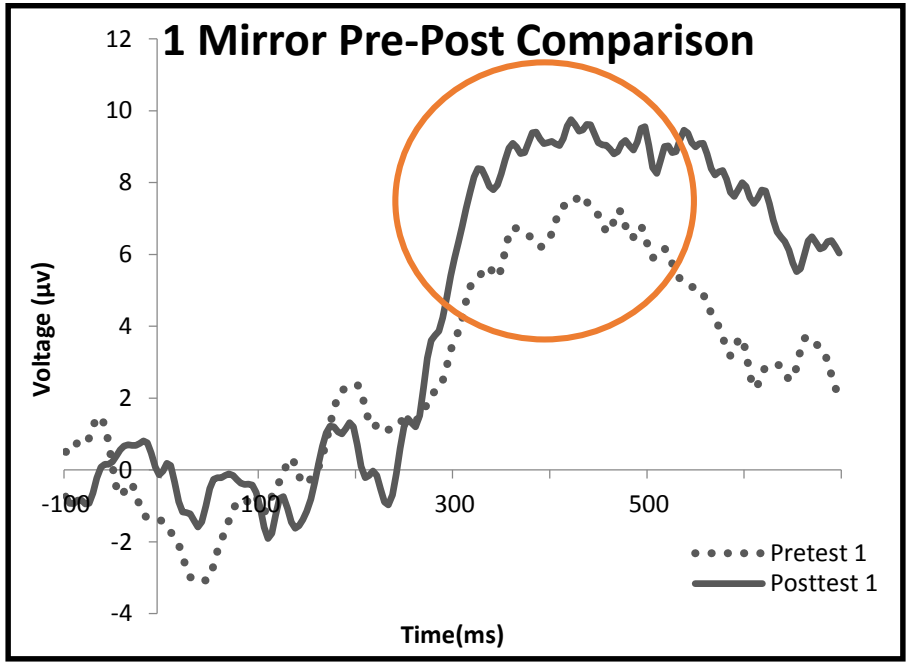
How do children learn this concept?

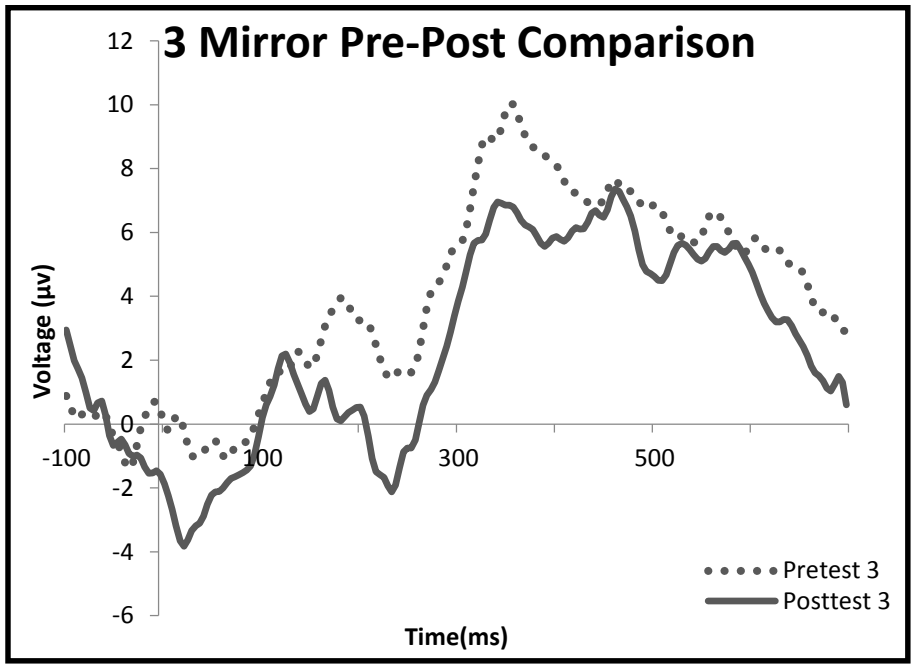

F3 LDLPFC (12)
F4 RDLPFC (60)
Pz Parietal & PP (36)
63
62
64
17
10
Fp1
5
Fp2
8
61
1
6
Fz
9
18
F7
12
F3
60
F4
58
F8
59
19
57
56
23
4
7
54
53
55
15
16
51
20
C3
REF
Cz
50
C4
22
49
24
T3
52
T4
21
41
25
26
46
48
27
COM
28
P3
42
P4
45
29
LM
34
Pz
47
RM
30
T5
31
40
44
T6
33
36
38
32
43
35
O1
37
Oz
39
O2
S/N

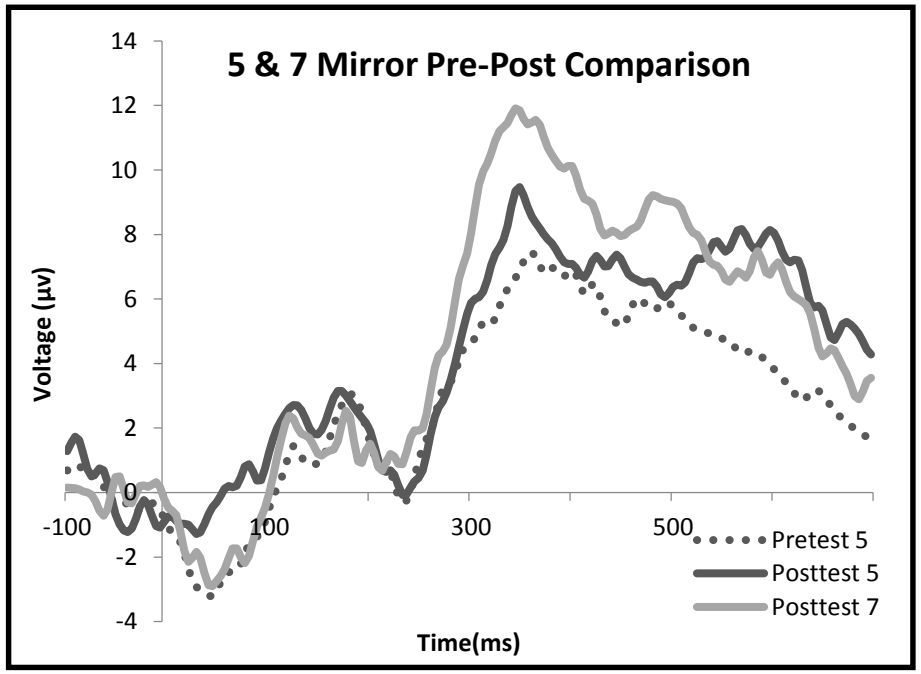
Overall; Pre-Test, Posttest; F3, F4, PostParietal

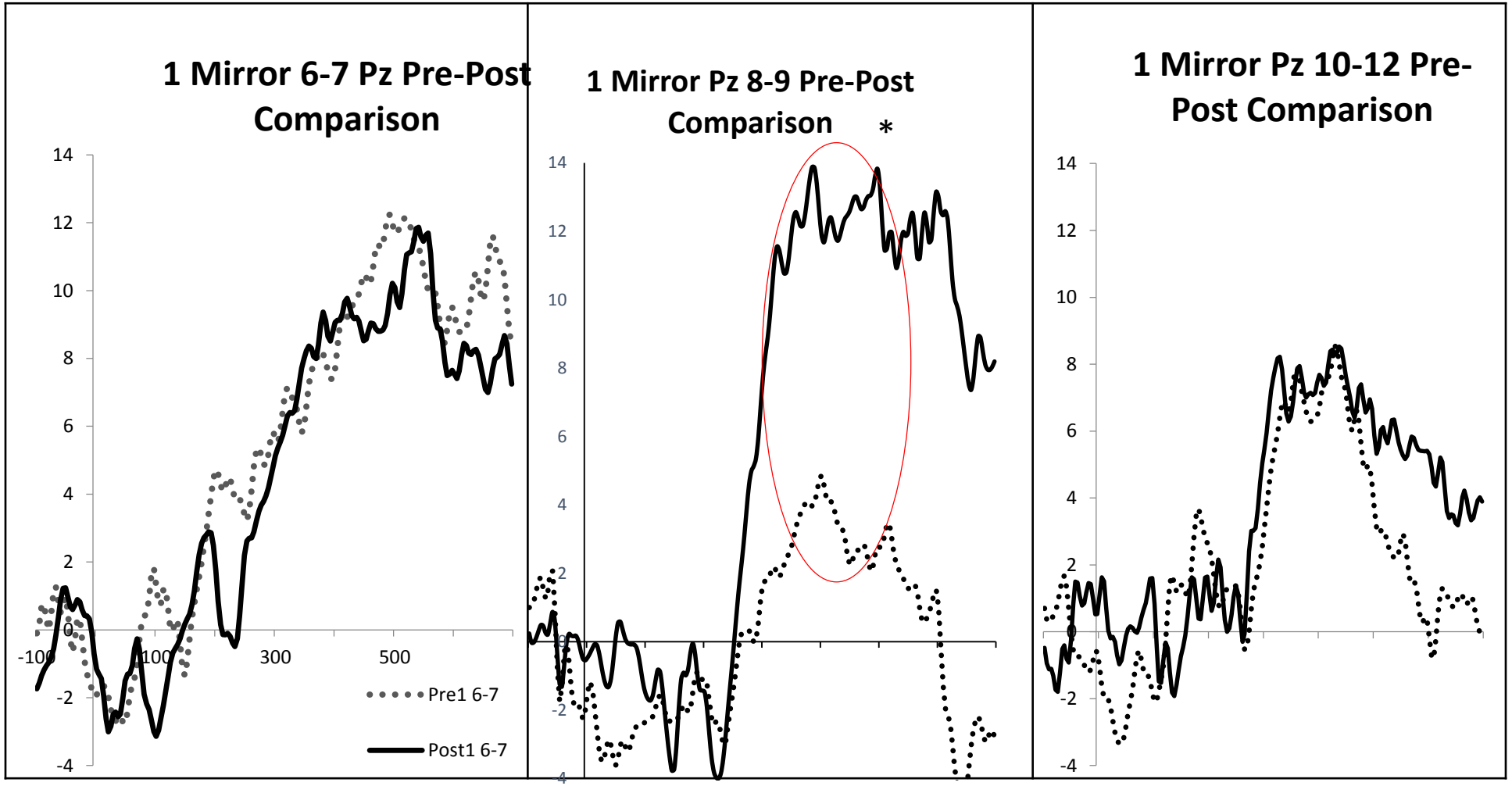
Phase 1
ERPs & Topo Maps

ERPs @36- Posterior Parietal








1 Mirror 6-7 Pz Pre-Post Comparison
14
12
10
8
6
4
2
0
-2
-4
-100
100
300
500
Pre1 6-7
Post1 6-7
1 Mirror Pz 8-9 Pre-Post Comparison *
14
12
10
8
6
4
2
-2
-4
1 Mirror Pz 10-12 Pre-Post Comparison
14
12
10
8
6
4
2
0
-2
-4

F3 N200 ERP Statistical Differences

- **Interaction between Block, Gender, and Developmental Level**
  - **F (4, 30)= 4.817, p<.005 η^2 = .39, Power=.92**

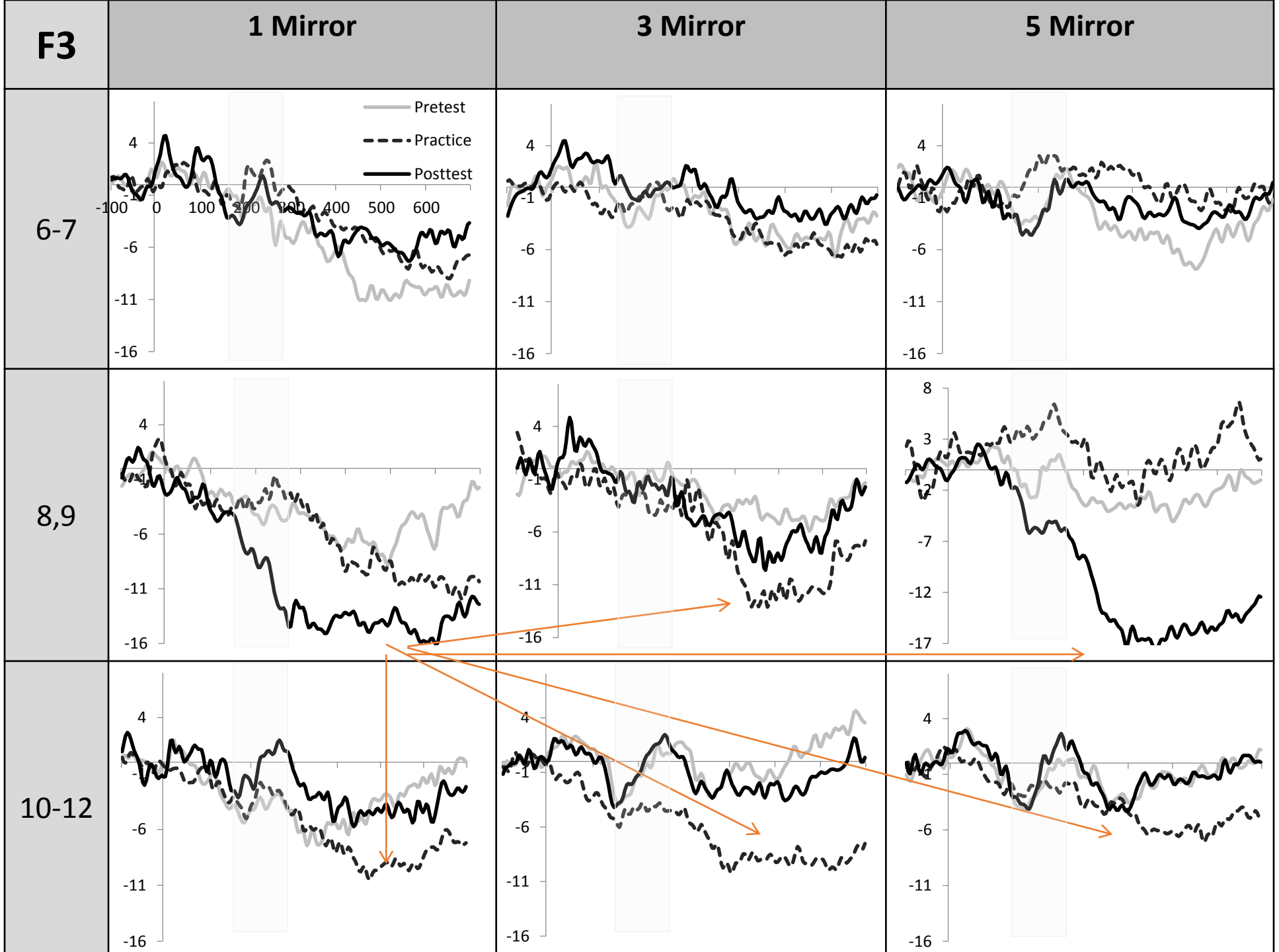
- **Interaction between Block, Mirror, and Gender**
  - **F (4, 60)= 3.466, p<.05 η^2 = .19, Power=.83**

- **Interaction between Block, Mirror, Gender, and Developmental Level**
  - **F (8,60)= 2.437, p<.05 η^2 = .25, Power=.86**

Developmental Performance

No significant differences Pretest ($F=.292$, $p=.589$)

Significant differences during the
Practice ($F=14.72$, $p<.001$)
Posttest ($F=13.25$; $p<.001$)


F3
1 Mirror
3 Mirror
5 Mirror
6-7
8,9
10-12
Pretest
Practice
Posttest
-100
0
100
200
300
400
500
600
4
-1
-6
-11
-16
8
3
-2
-7
-12
-17

ERPs Compared to Performance

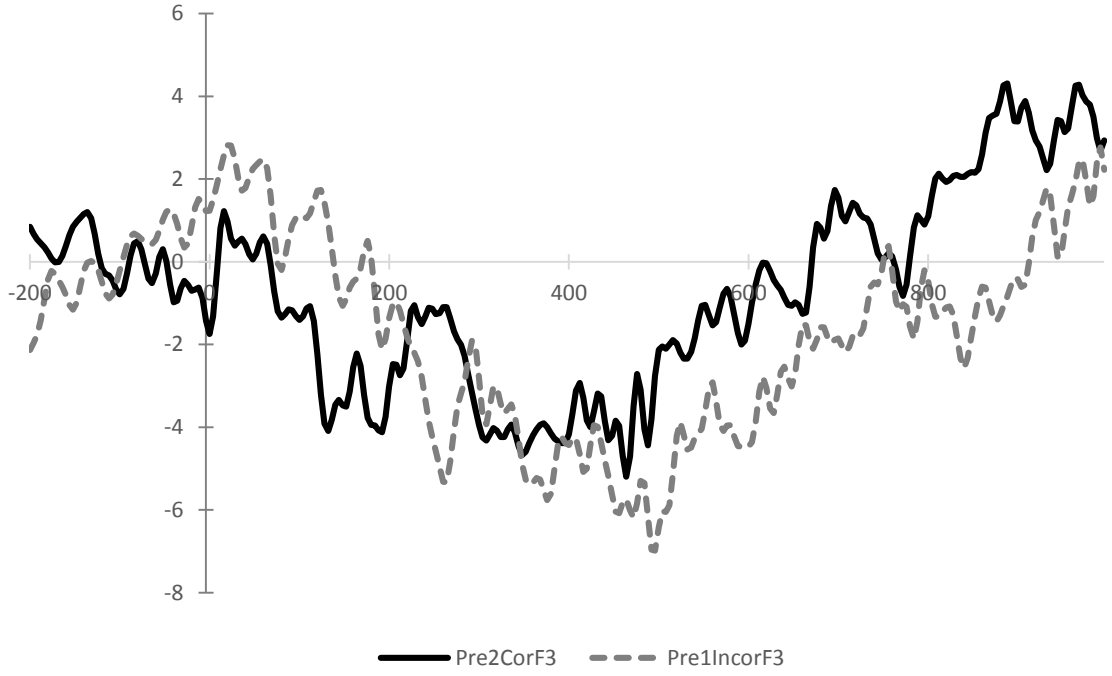
- Left Superior Frontal Sulcus
  - Developmental Differences 6/7 to 8-12
  - Male/Female Differences N2 & Slow Wave

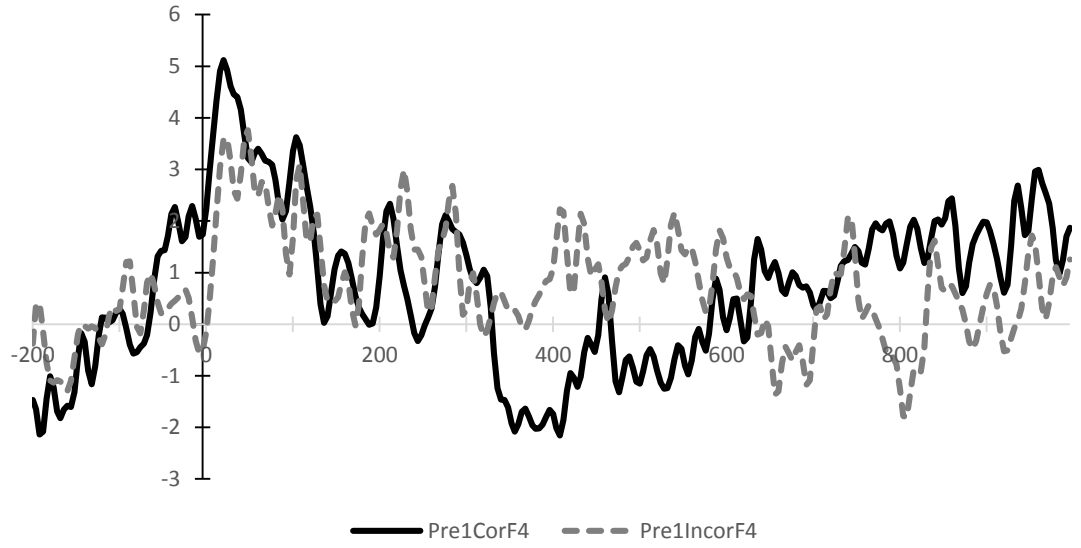
Liang et al 2006

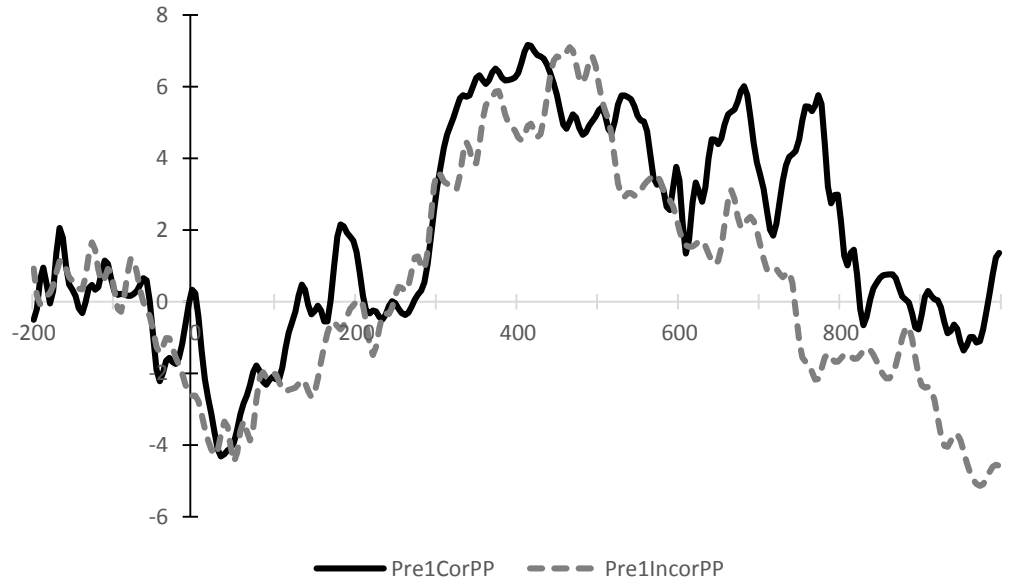
Correct vs. Incorrect;
Pre-Test, Posttest; F3, F4, PosteriorParietal

Phase 2
ERPs & Topo Maps

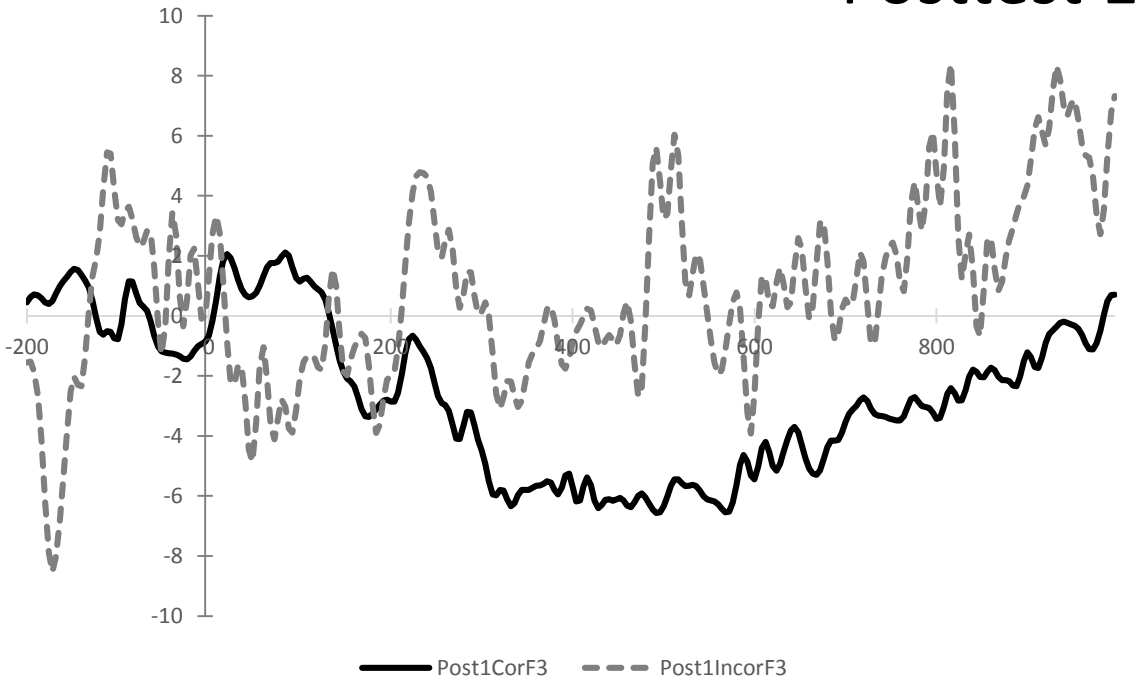
Pretest 1 Mirror

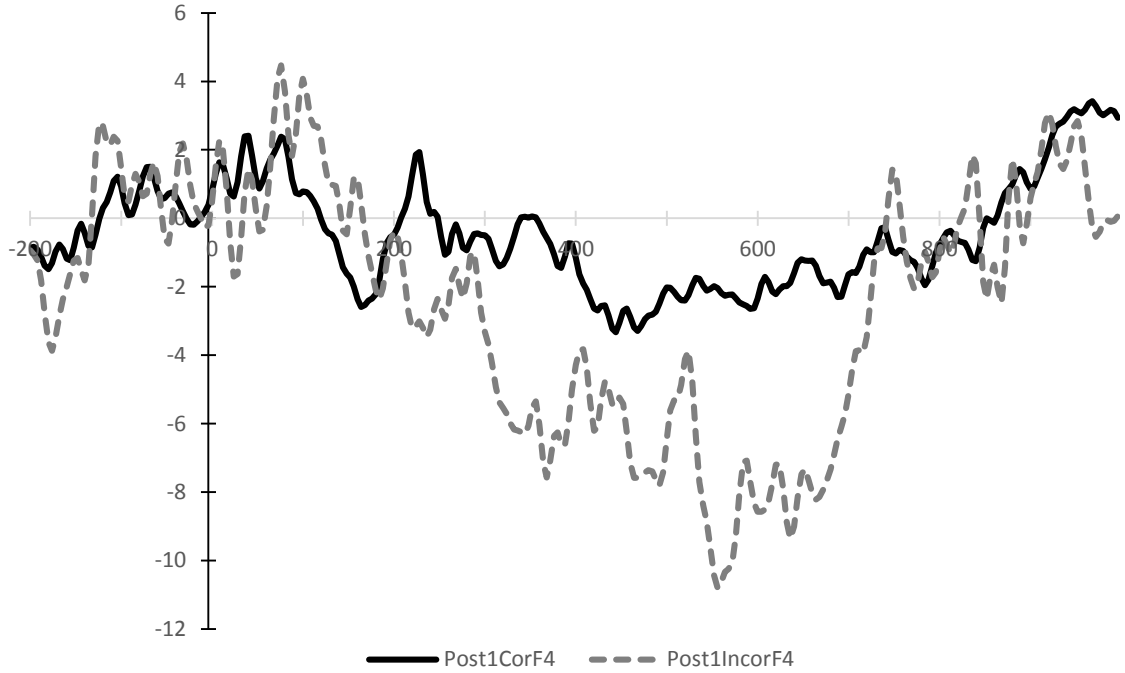


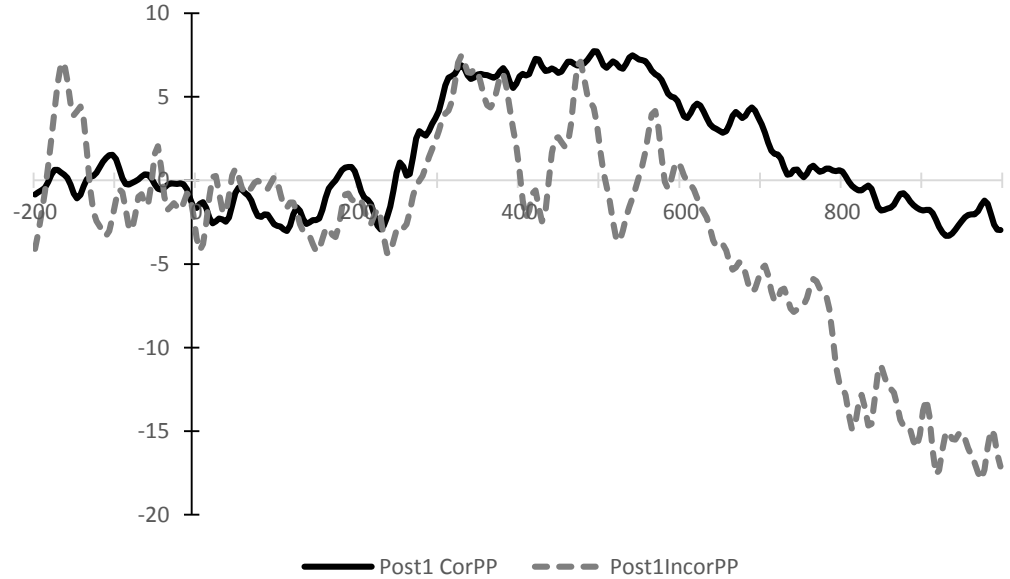


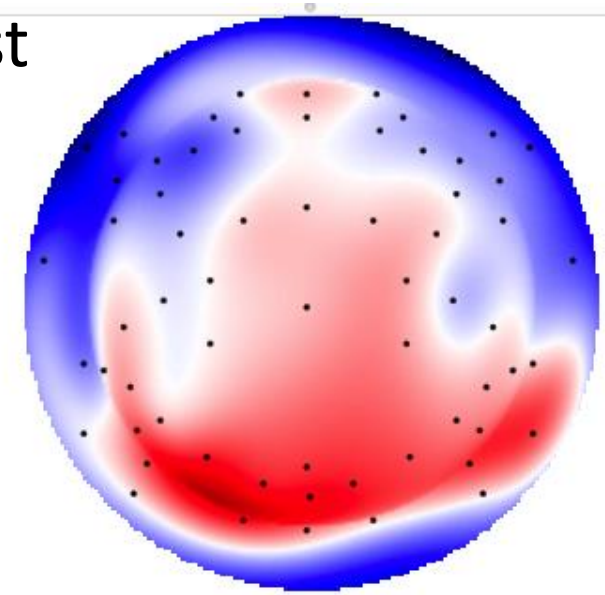
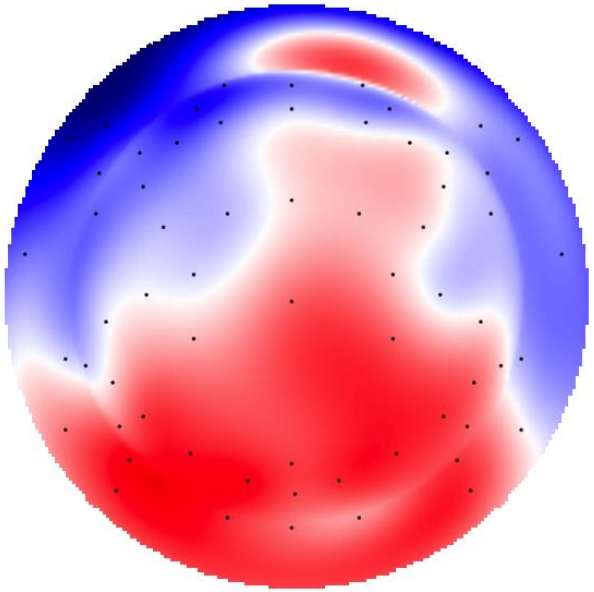
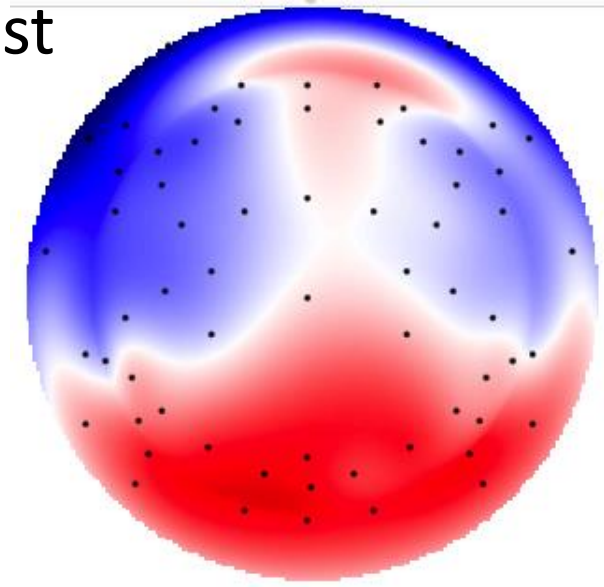
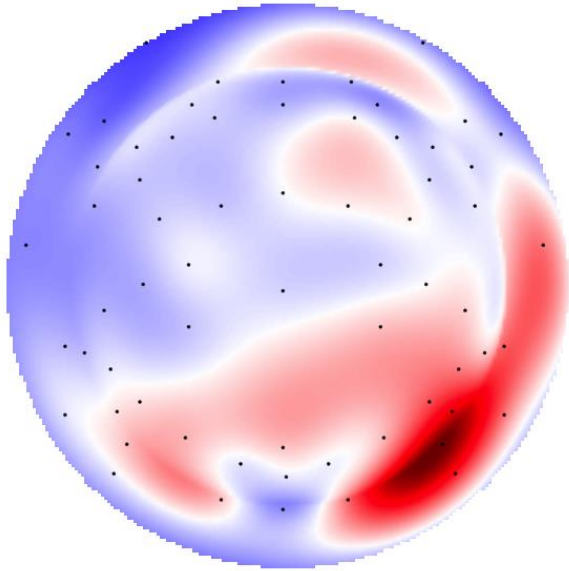


Posttest 1 Mirror

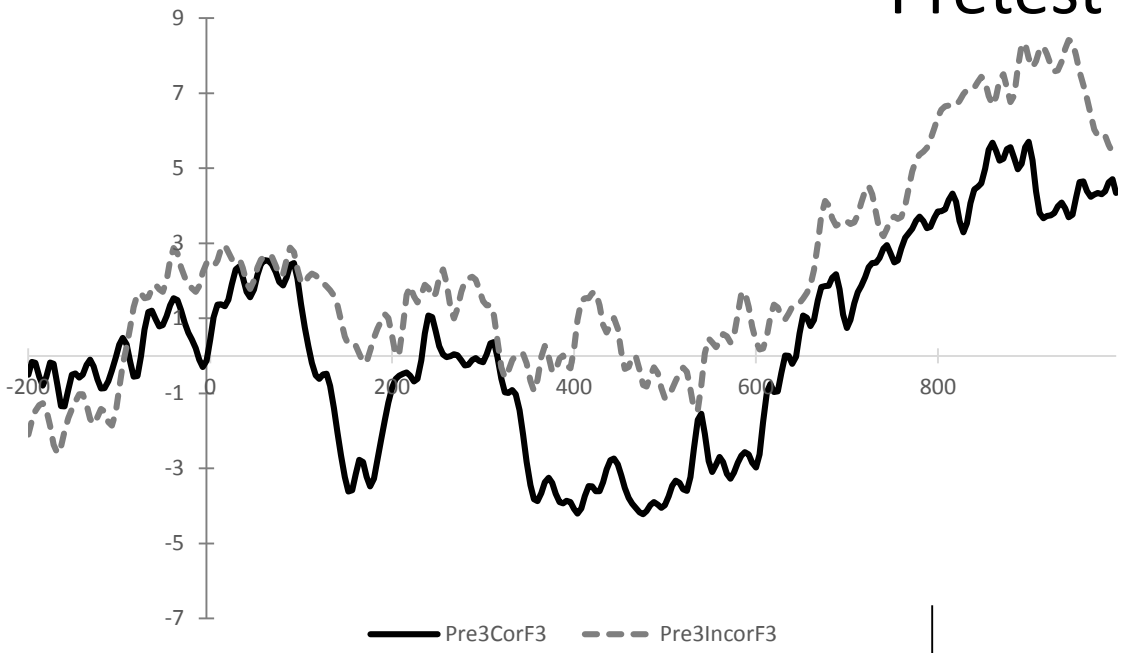


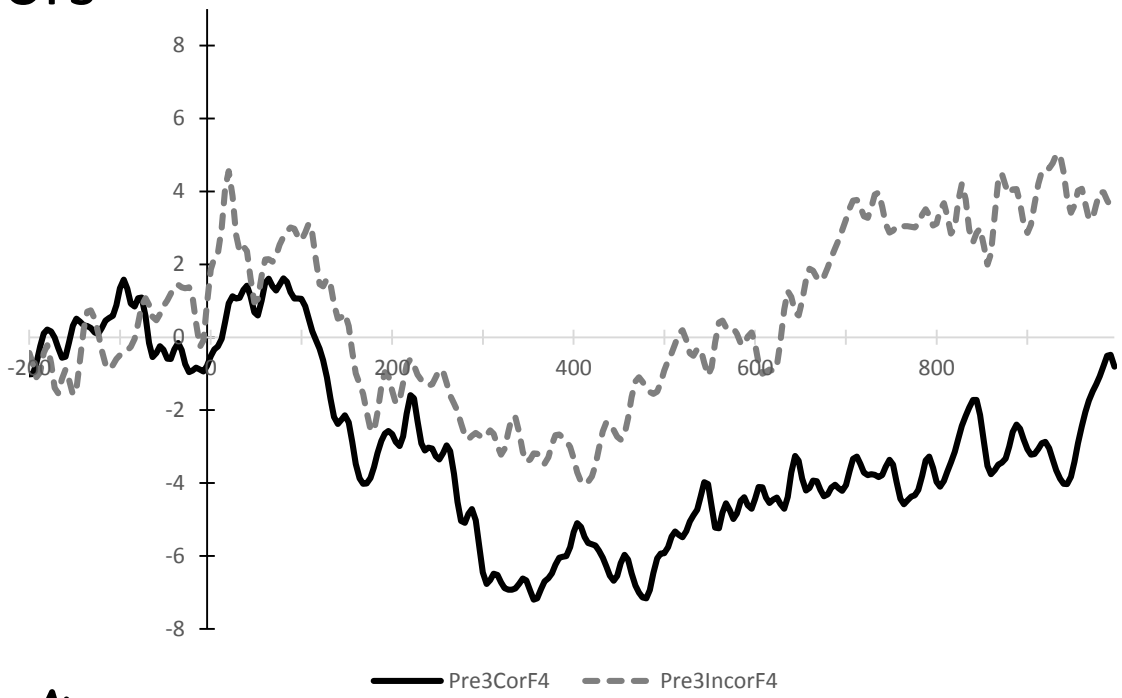


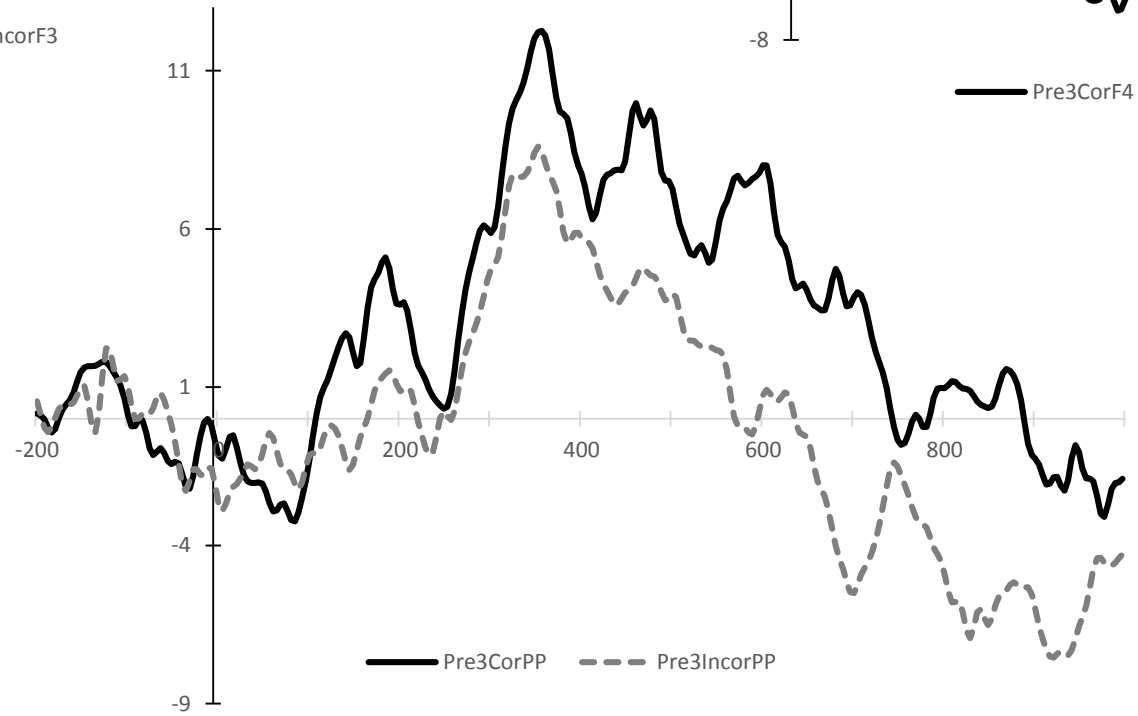


	Correct	Incorrect
Pretest		
Posttest		

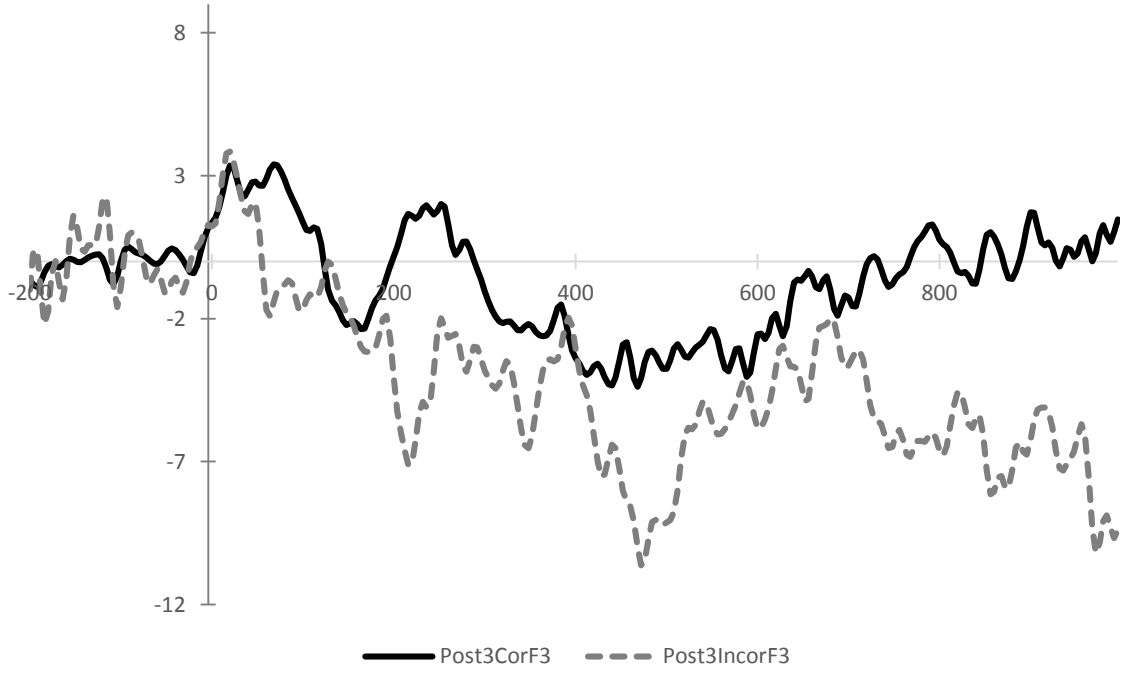
Pretest 3 Mirrors

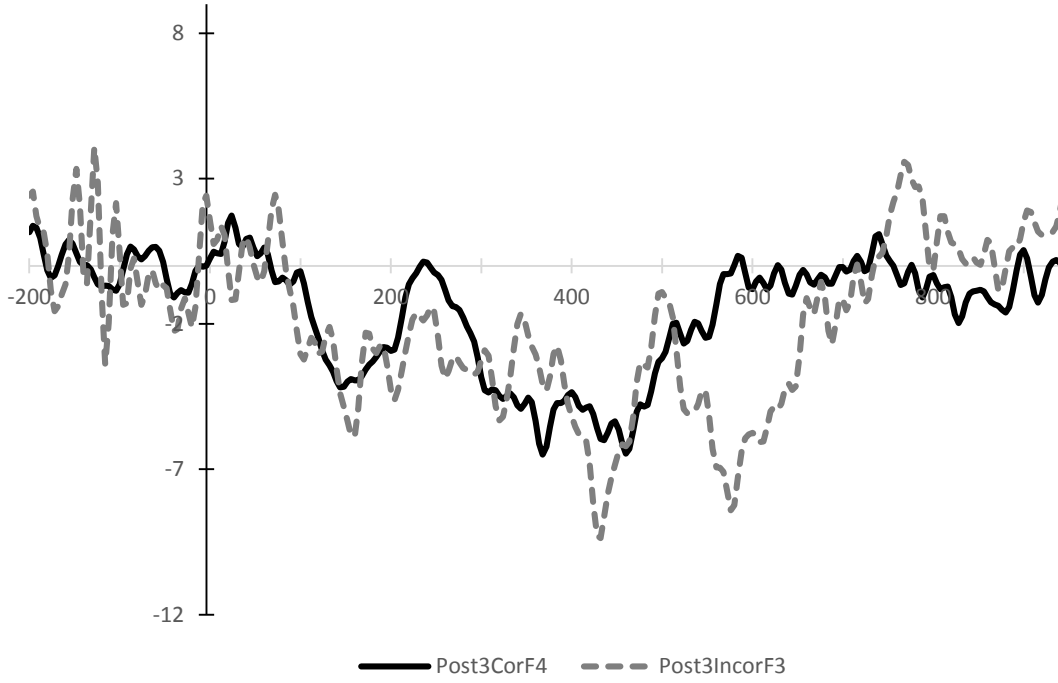


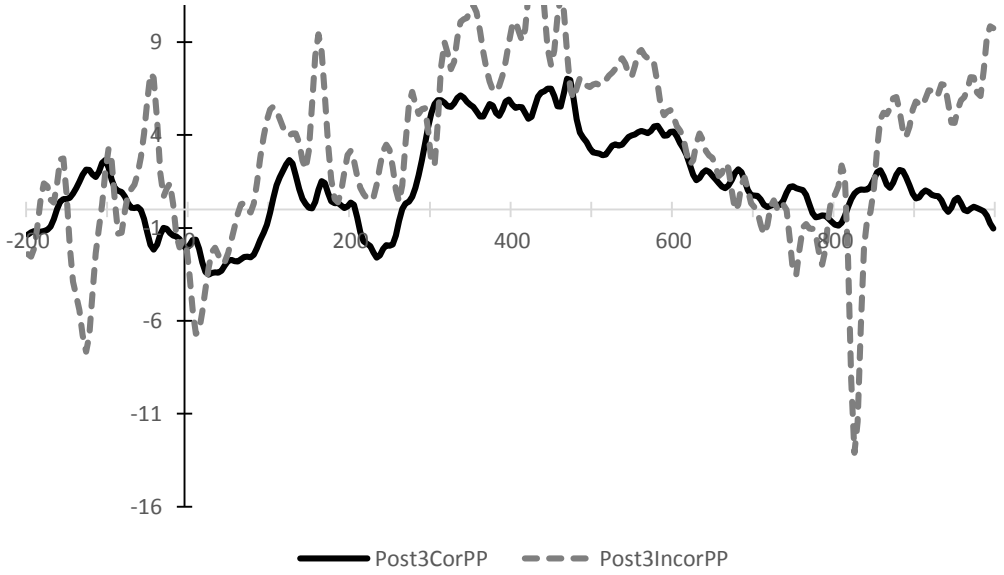


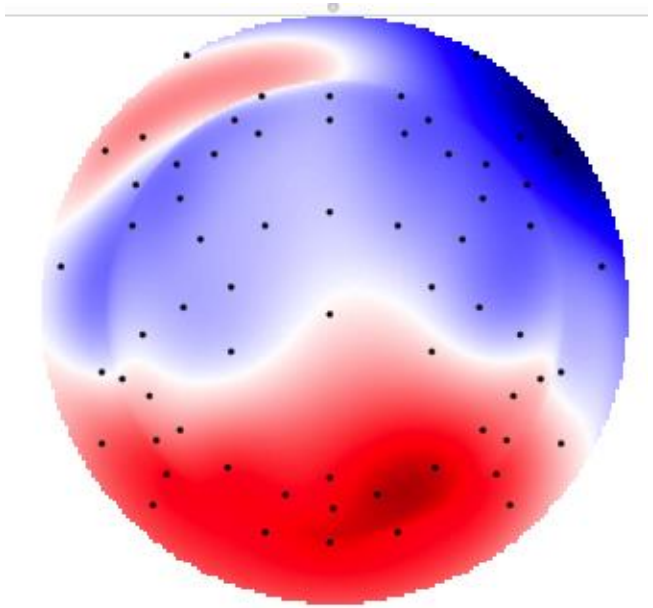
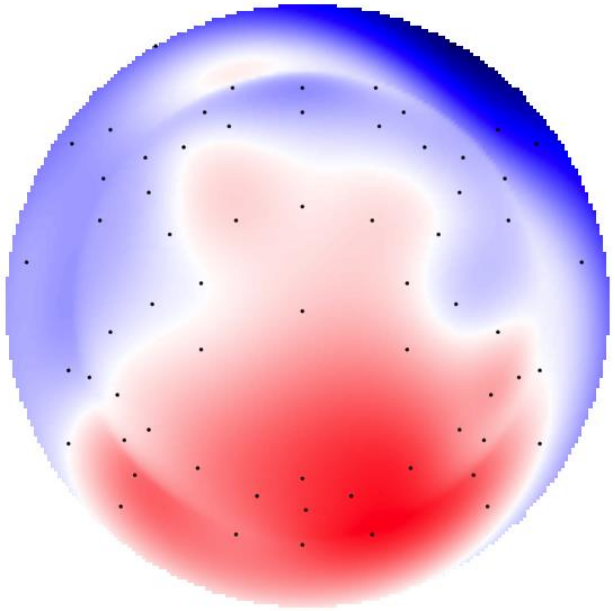
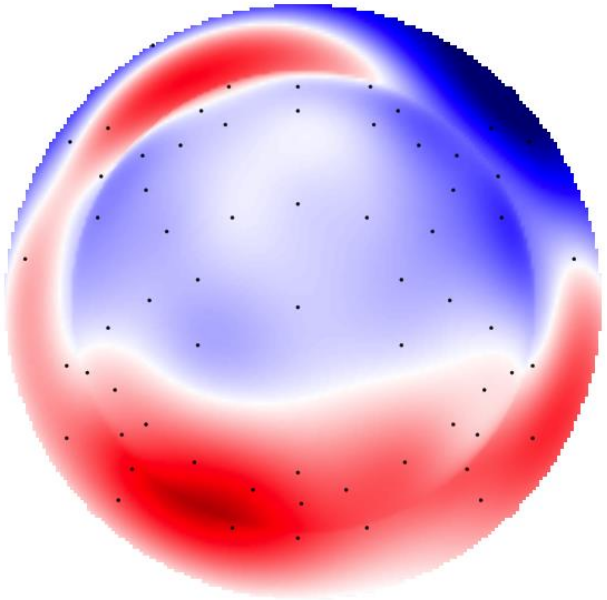
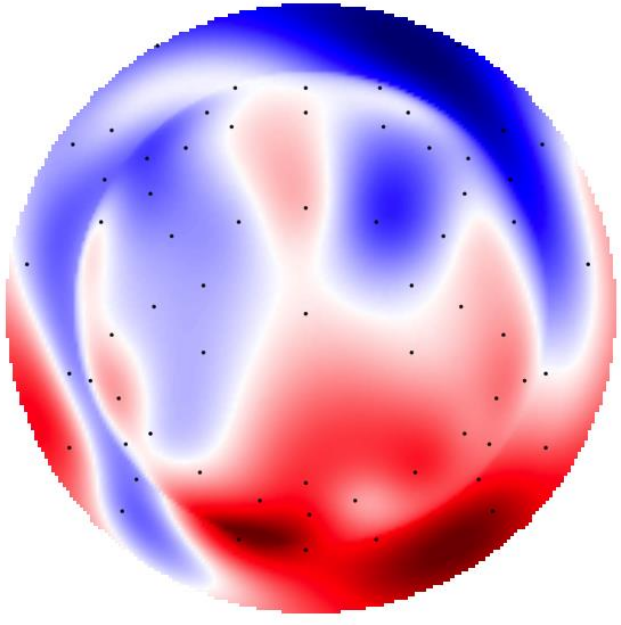


Posttest 3 Mirrors

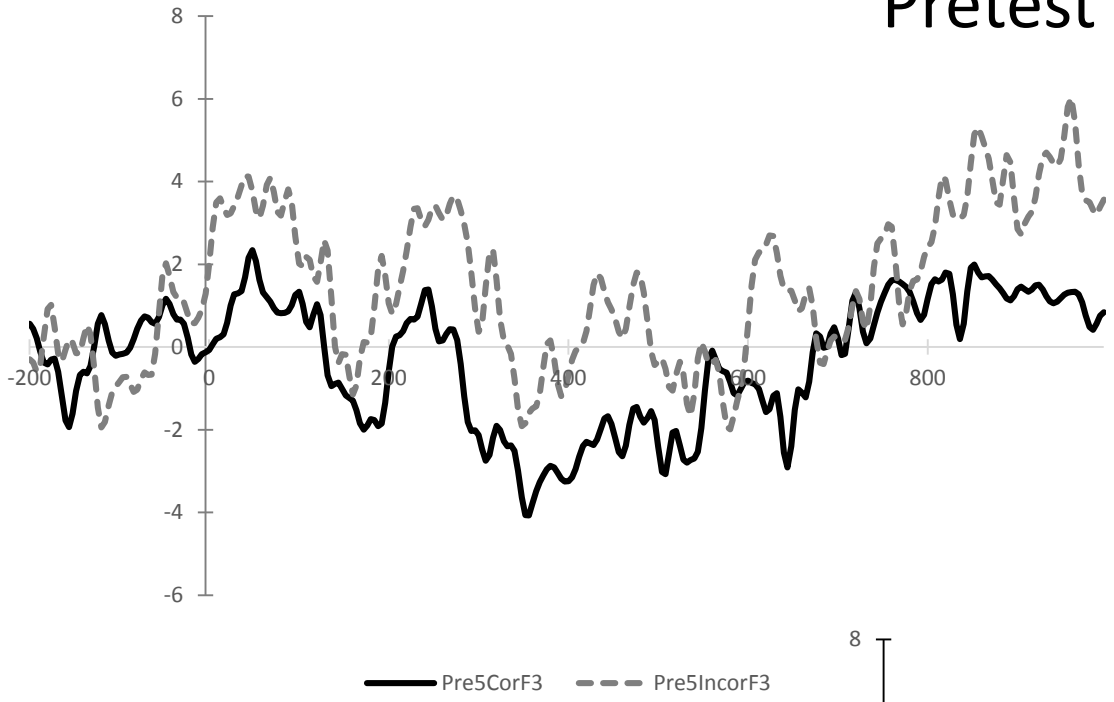


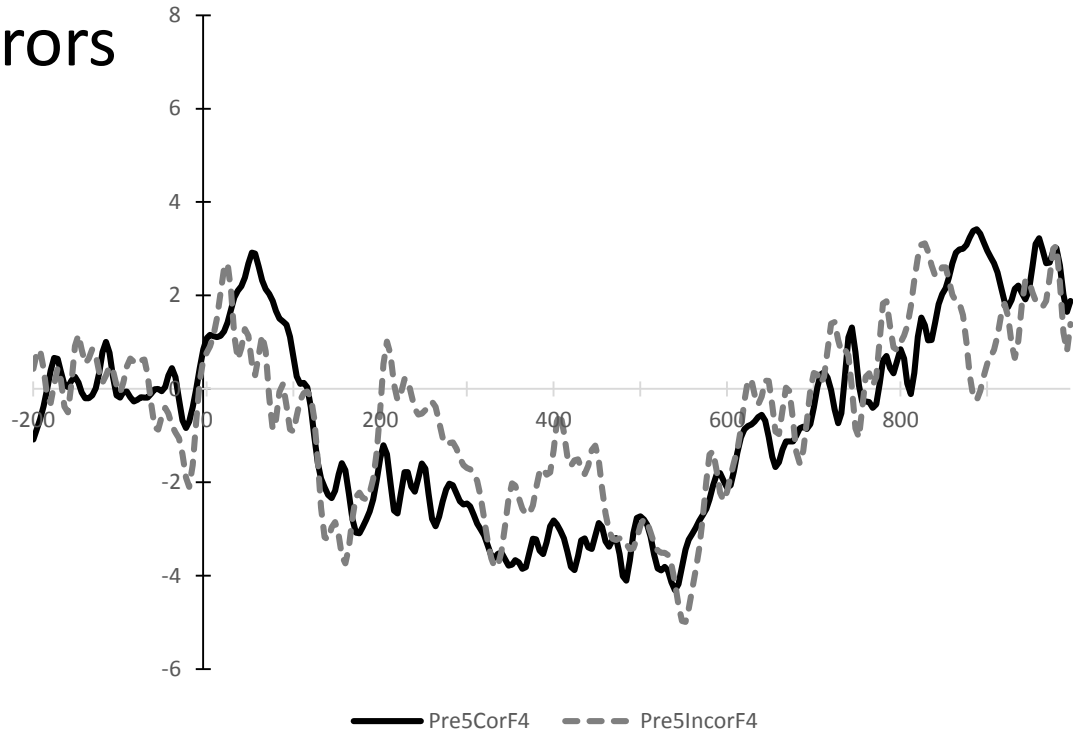


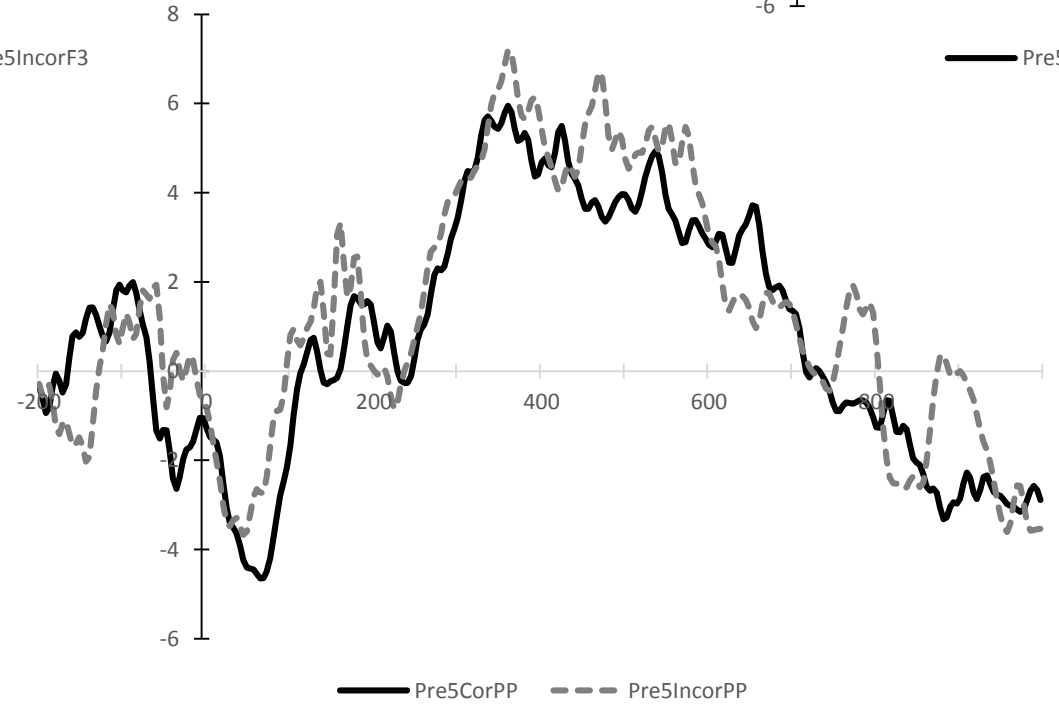


	Correct	Incorrect
Pretest		
Posttest		

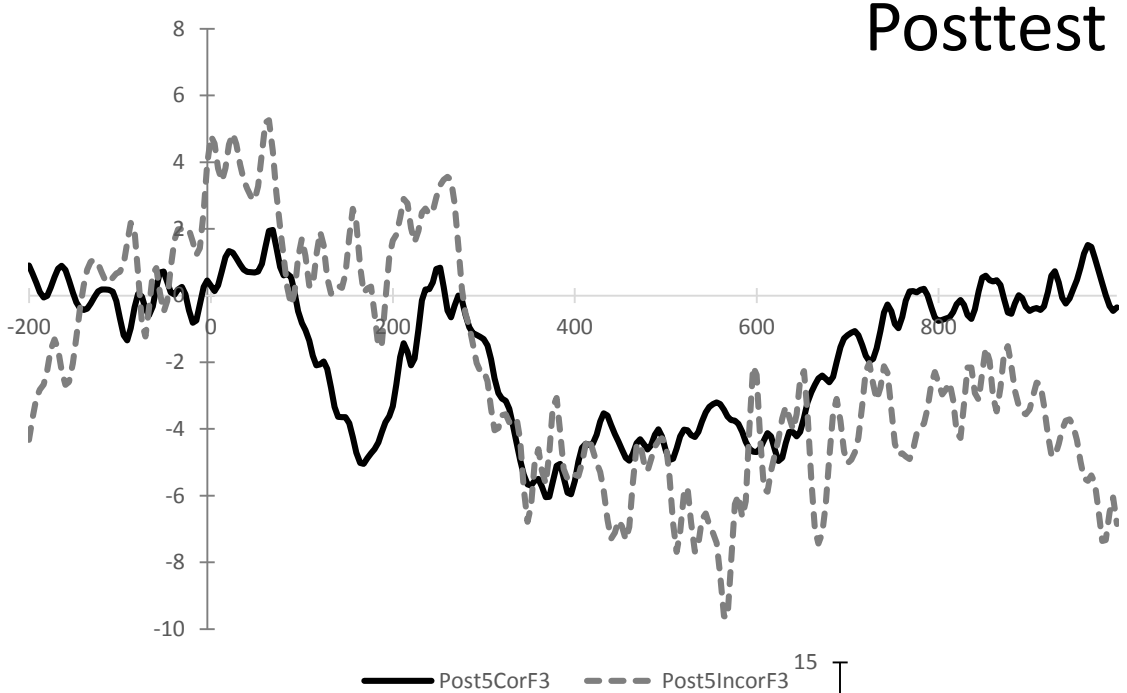
Pretest 5 Mirrors

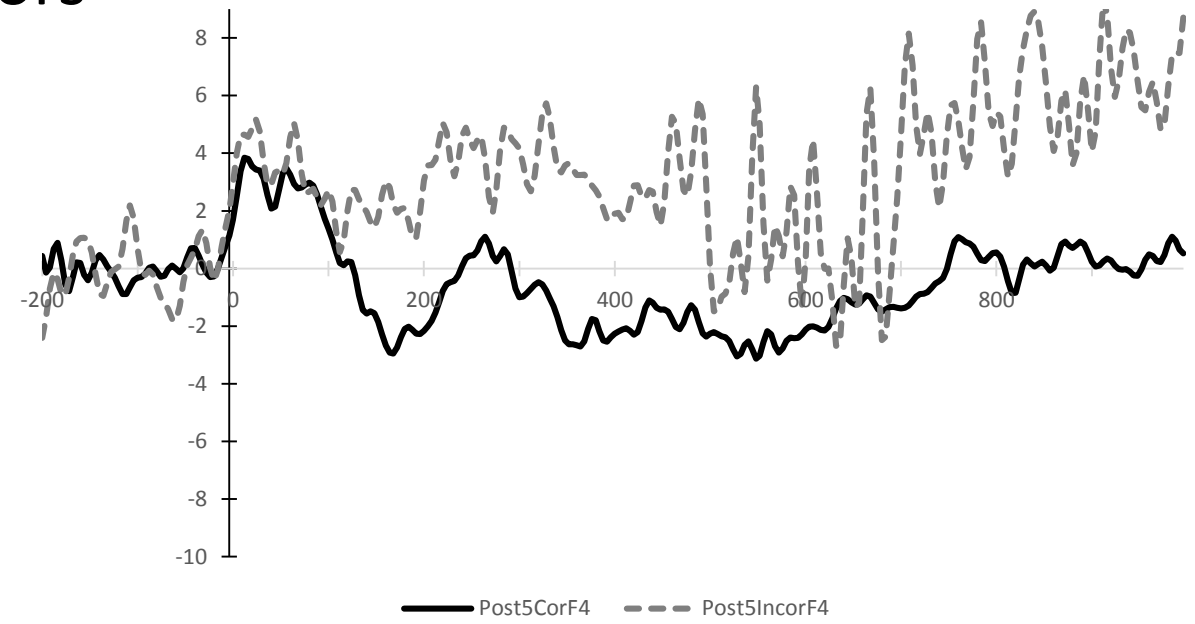


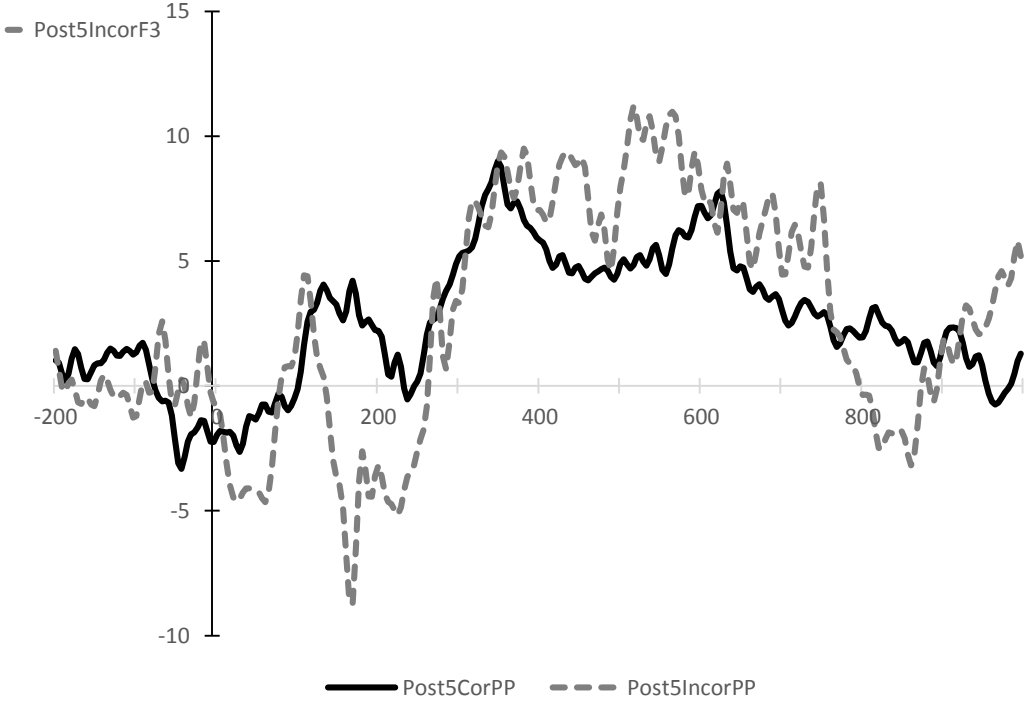


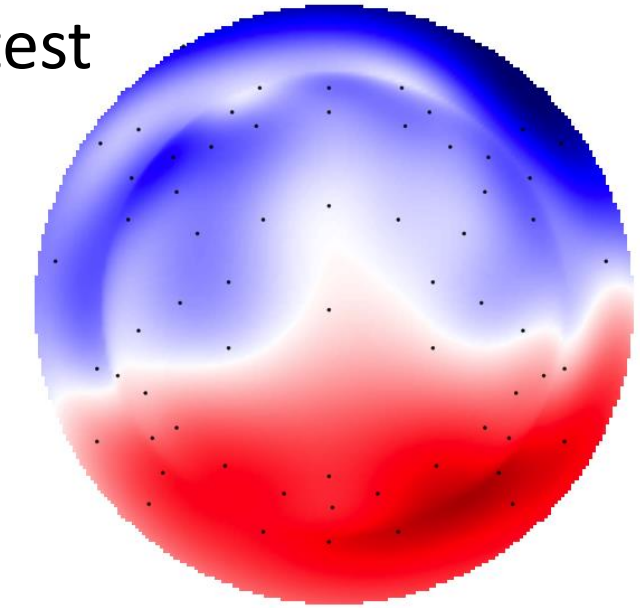
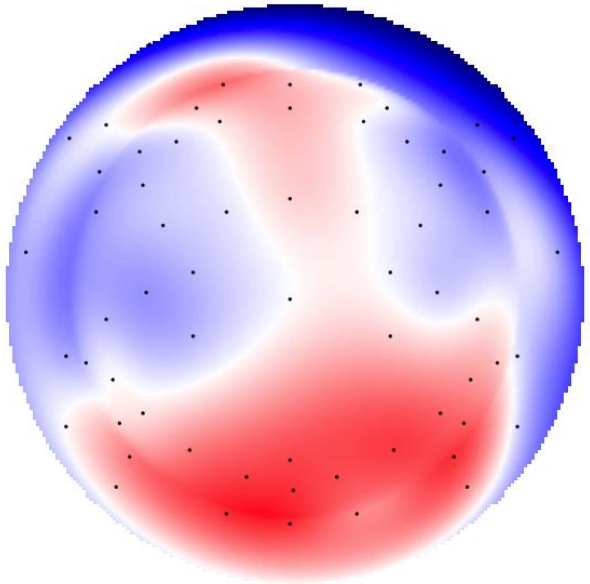
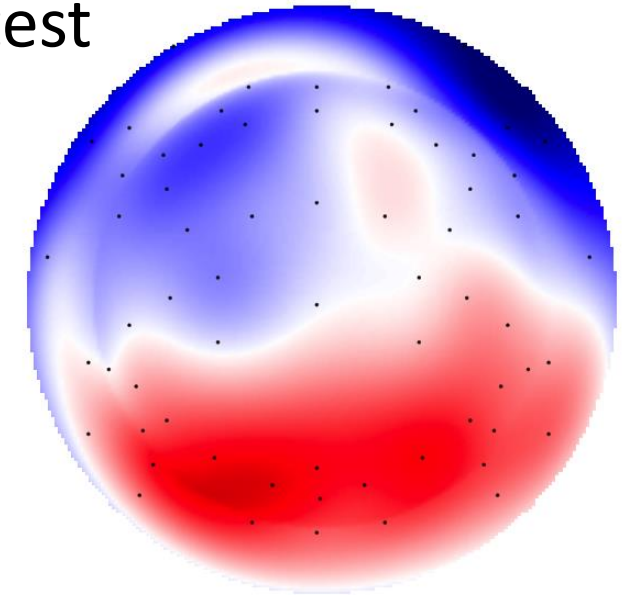
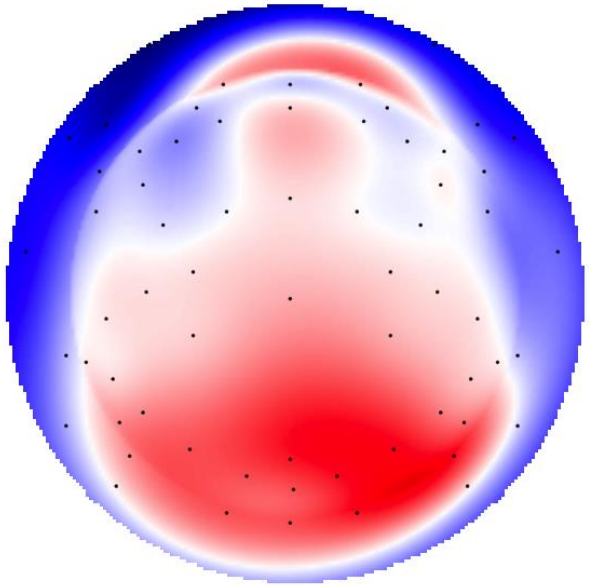


Posttest 5 Mirrors







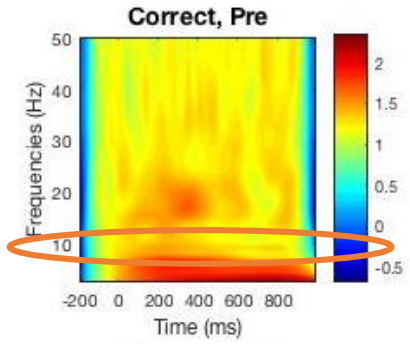
	Correct	Incorrect
Pretest		
Posttest		

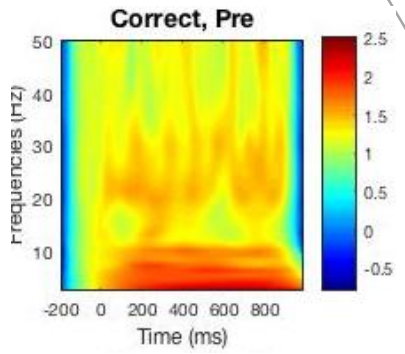
Correct vs. Incorrect;
Pre-Test, Posttest; F3, F4, PostParietal

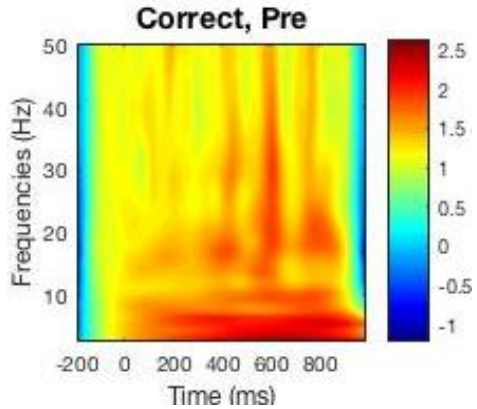
Phase 3
Joint Time Frequency

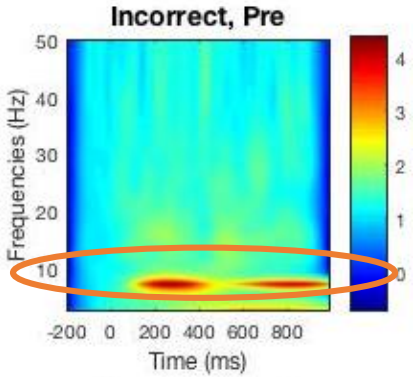
Pretest

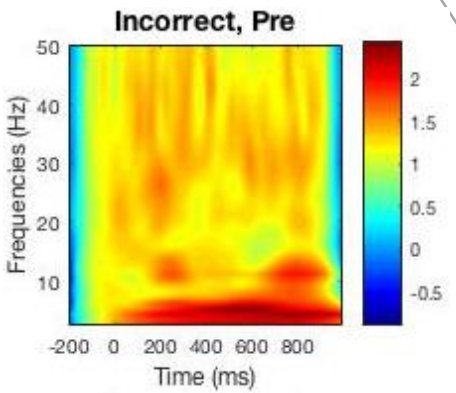
1 Mirror

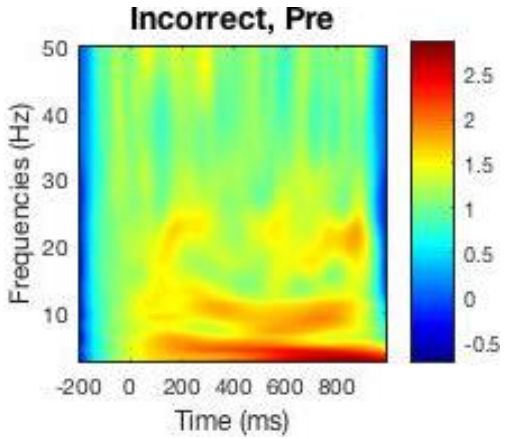

Correct, Pre
Frequencies (Hz)
Time (ms)


Correct, Pre
Frequencies (Hz)
Time (ms)

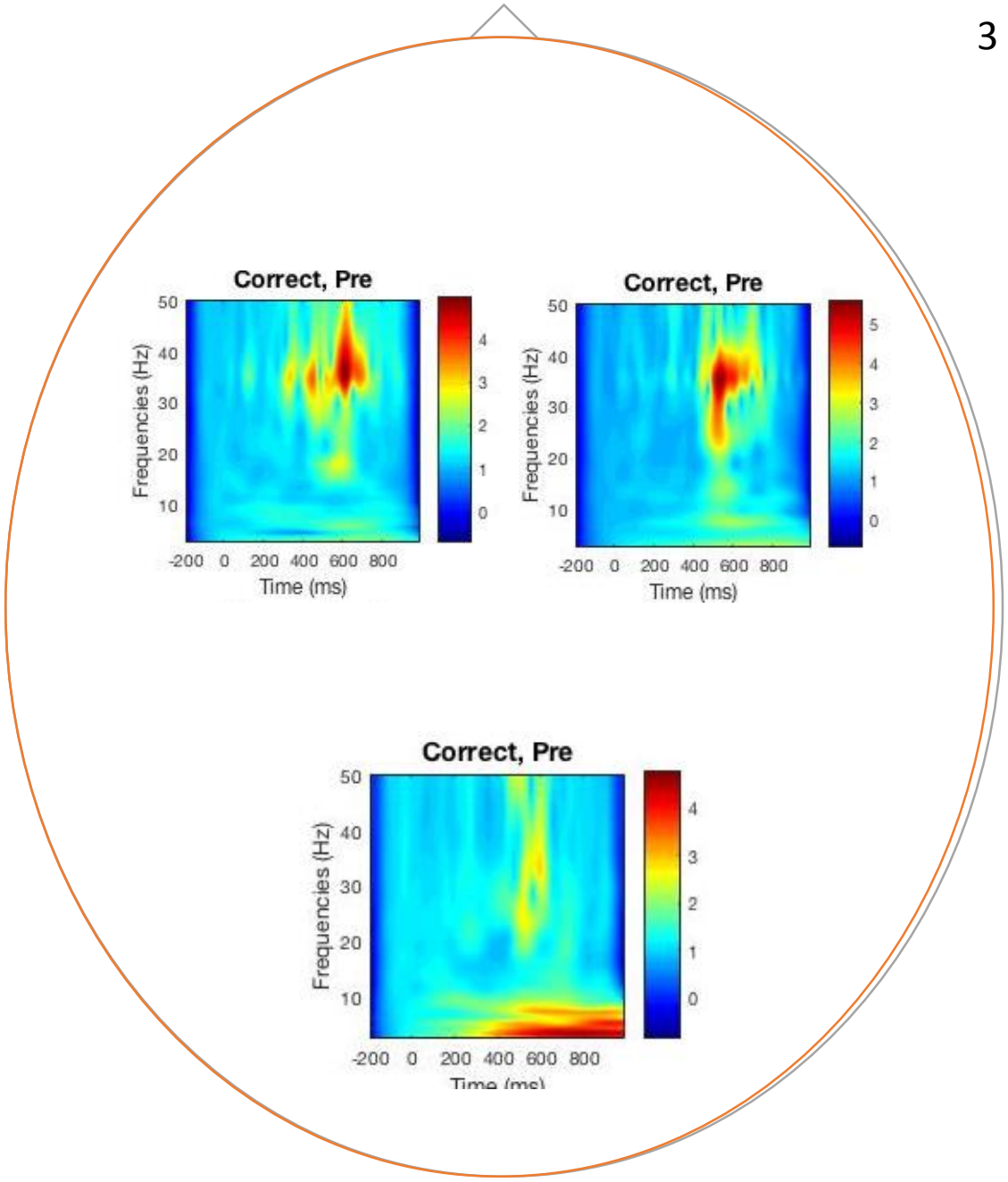

Correct, Pre
Frequencies (Hz)
Time (ms)

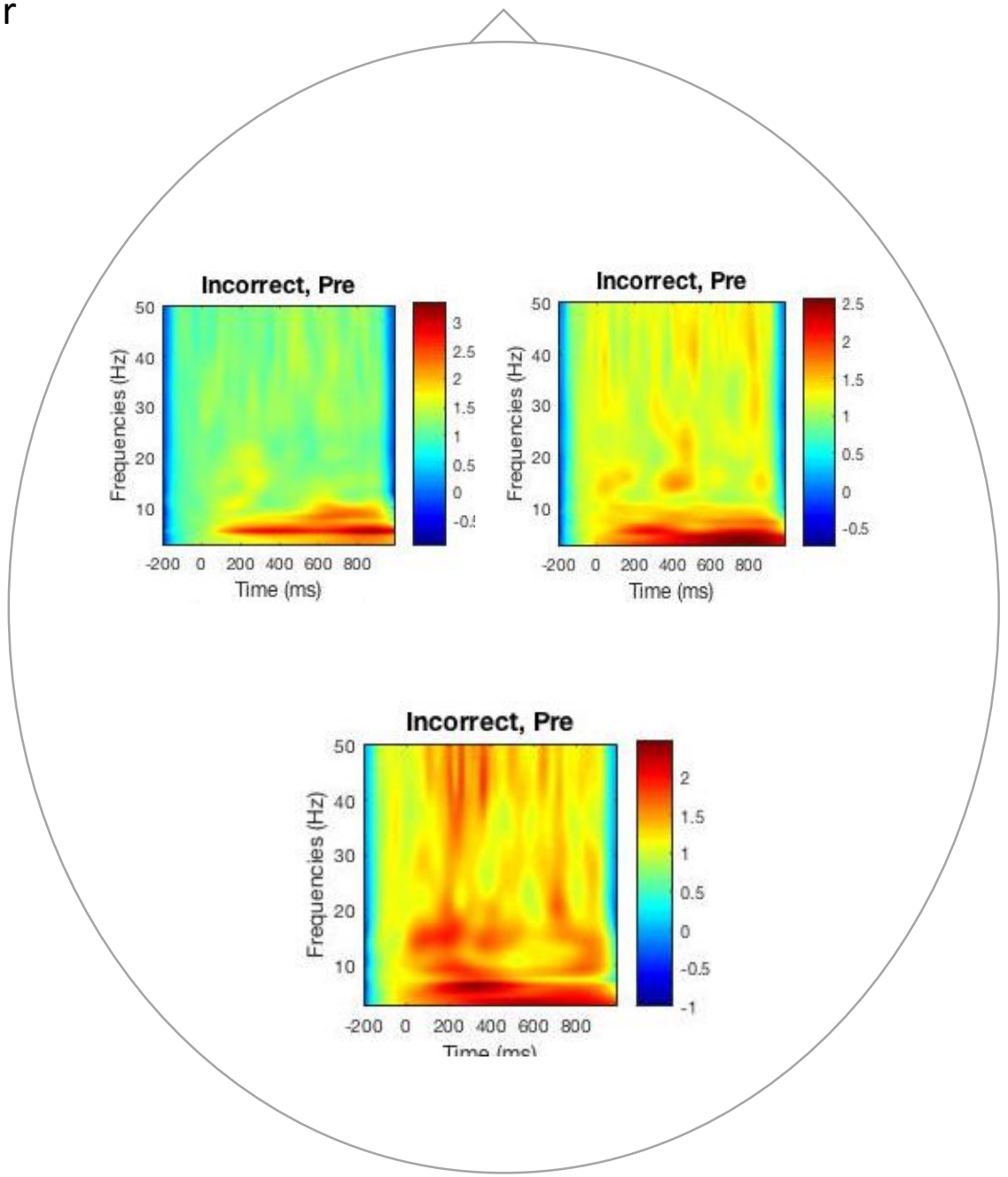

Incorrect, Pre
Frequencies (Hz)
Time (ms)


Incorrect, Pre
Frequencies (Hz)
Time (ms)

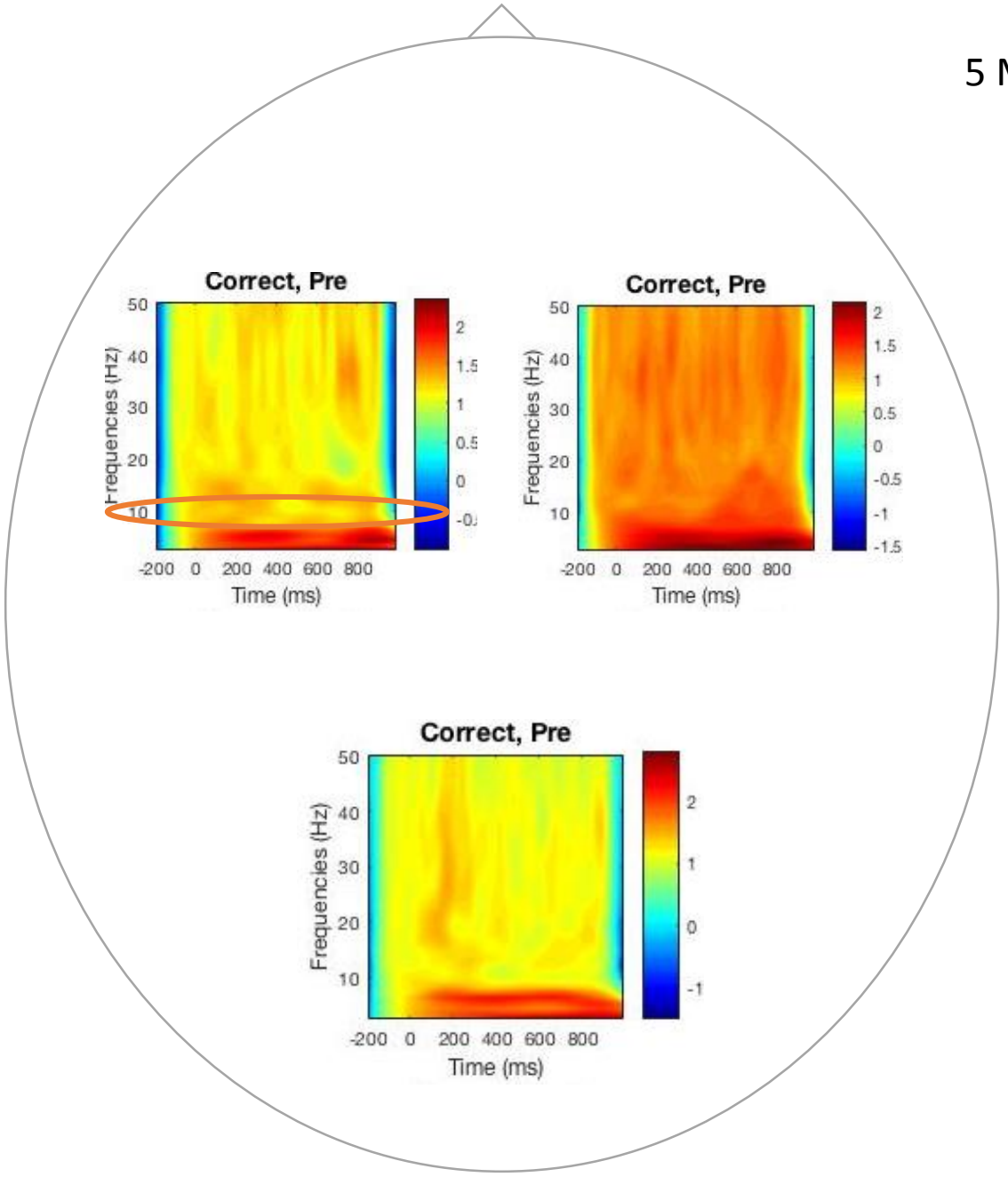

Incorrect, Pre
Frequencies (Hz)
Time (ms)

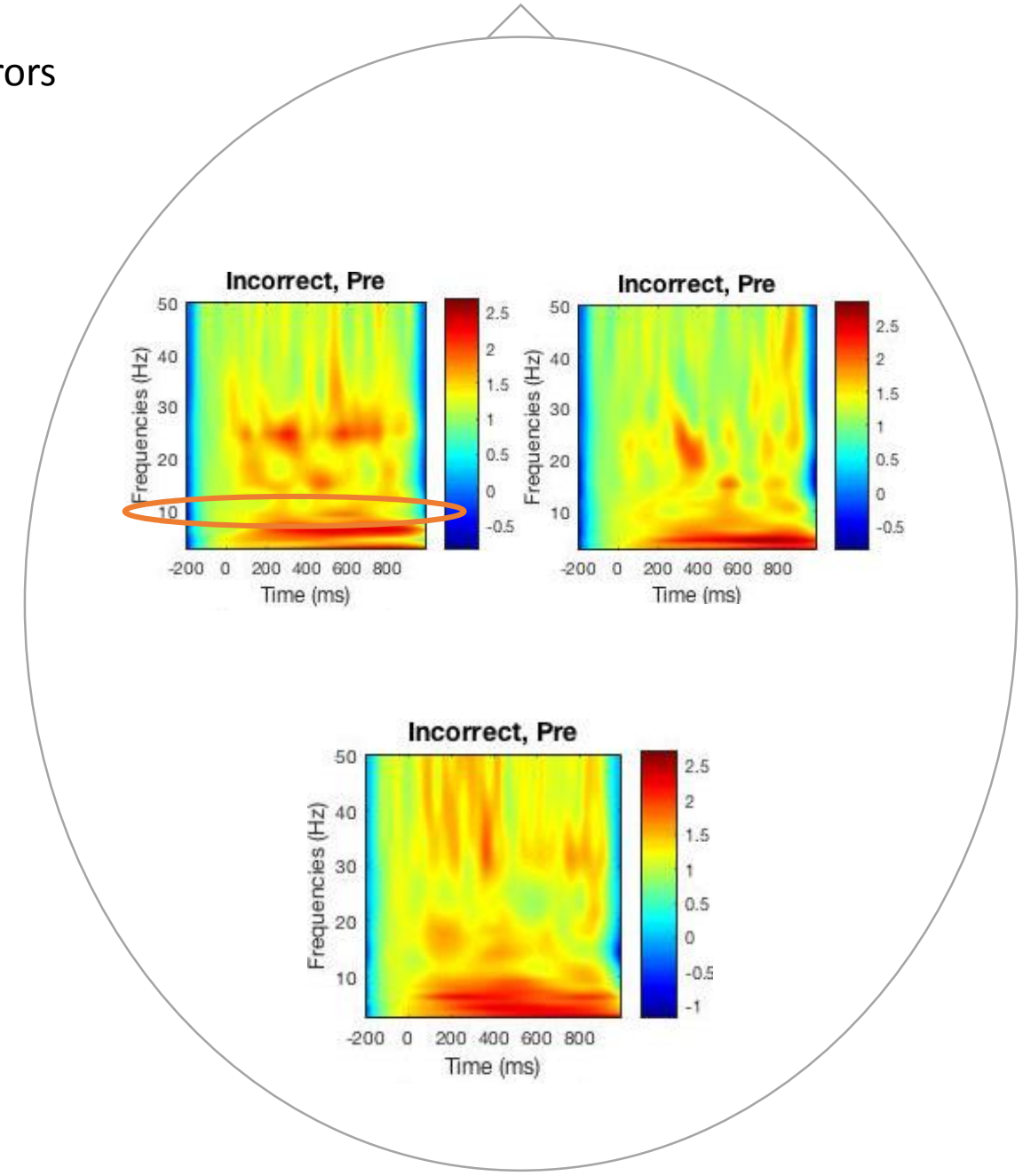
3 Mirror


Correct, Pre
Frequencies (Hz)
Time (ms)
Correct, Pre
Frequencies (Hz)
Time (ms)
Correct, Pre
Frequencies (Hz)
Time (ms)


Incorrect, Pre
Frequencies (Hz)
Time (ms)
Incorrect, Pre
Frequencies (Hz)
Time (ms)
Incorrect, Pre
Frequencies (Hz)
Time (ms)

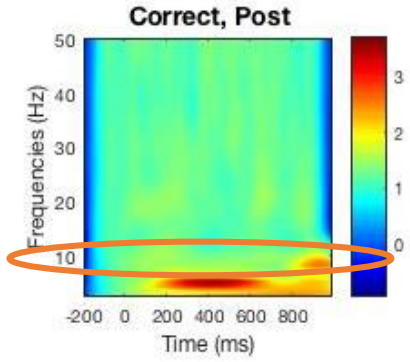
5 Mirrors

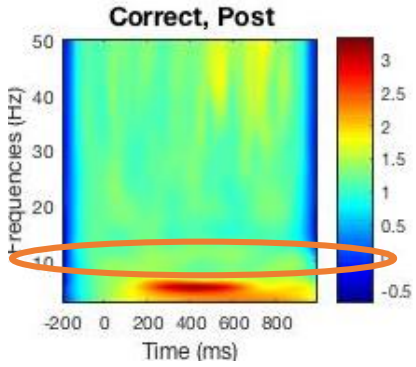

Correct, Pre
Frequencies (Hz)
Time (ms)
Correct, Pre
Frequencies (Hz)
Time (ms)
Correct, Pre
Frequencies (Hz)
Time (ms)

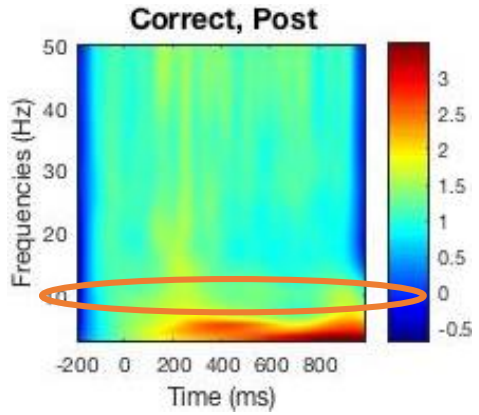

Incorrect, Pre
Frequencies (Hz)
Time (ms)
Incorrect, Pre
Frequencies (Hz)
Time (ms)
Incorrect, Pre
Frequencies (Hz)
Time (ms)

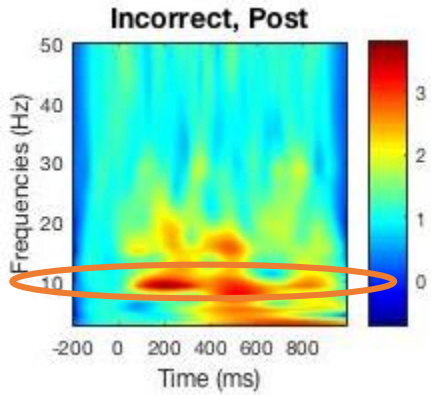
Posttest

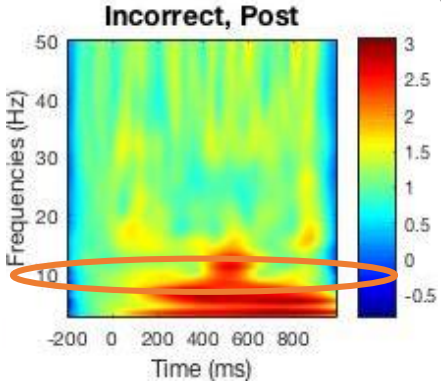
1 Mirror

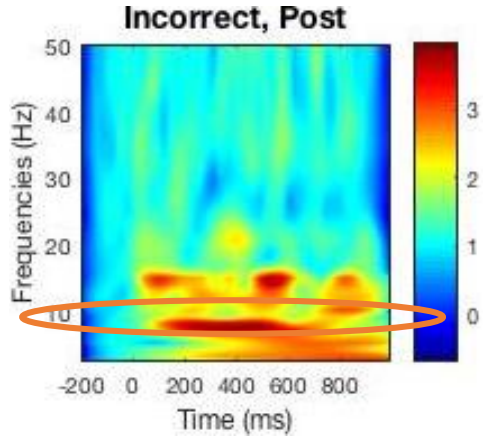

Correct, Post
Frequencies (Hz)
50
40
30
20
10
-200 0 200 400 600 800
Time (ms)
3
2
1
0


Correct, Post
Frequencies (Hz)
50
40
30
20
10
-200 0 200 400 600 800
Time (ms)
3
2.5
2
1.5
1
0.5
-0.5

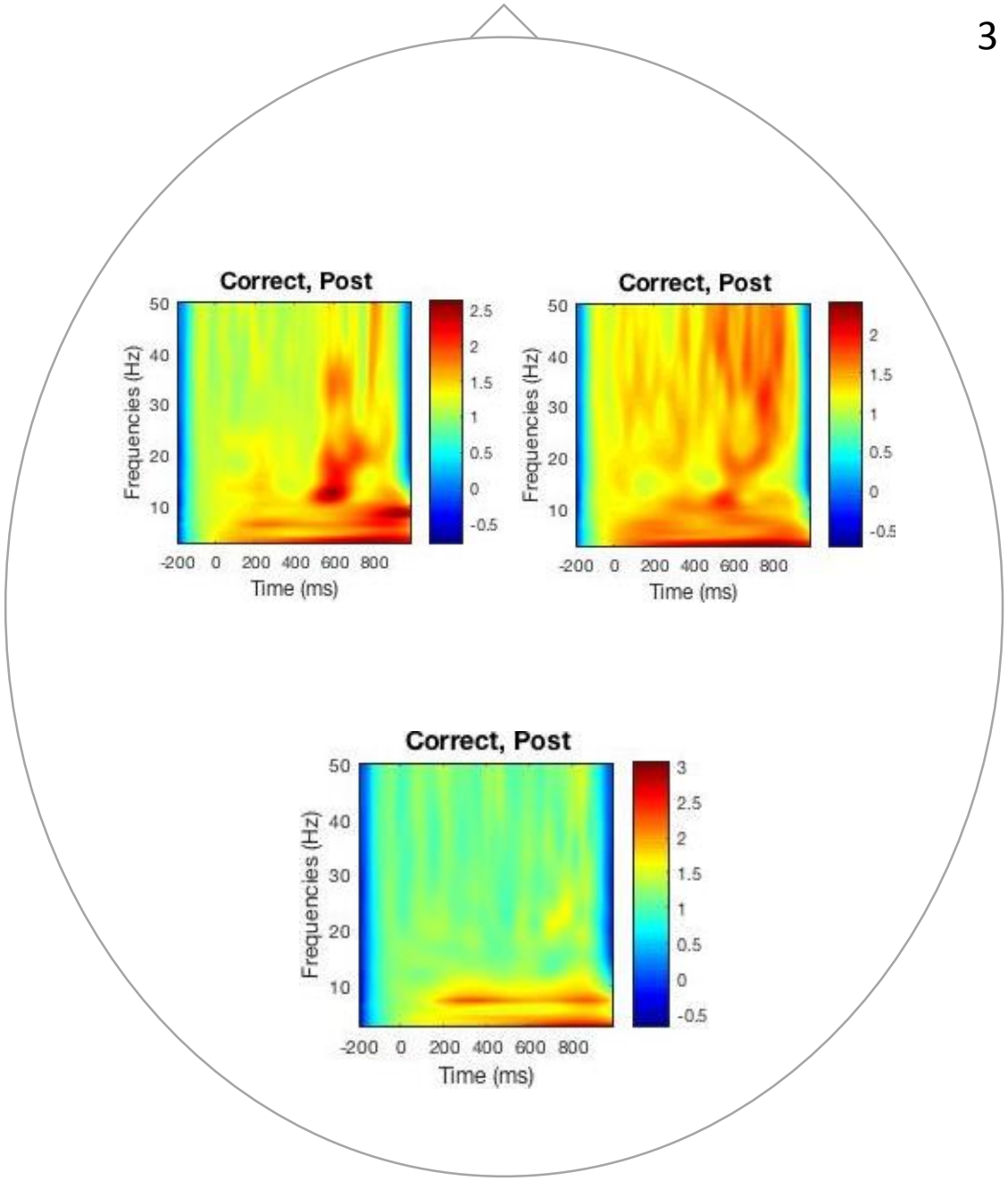

Correct, Post
Frequencies (Hz)
50
40
30
20
-200 0 200 400 600 800
Time (ms)
3
2.5
2
1.5
1
0.5
0
-0.5

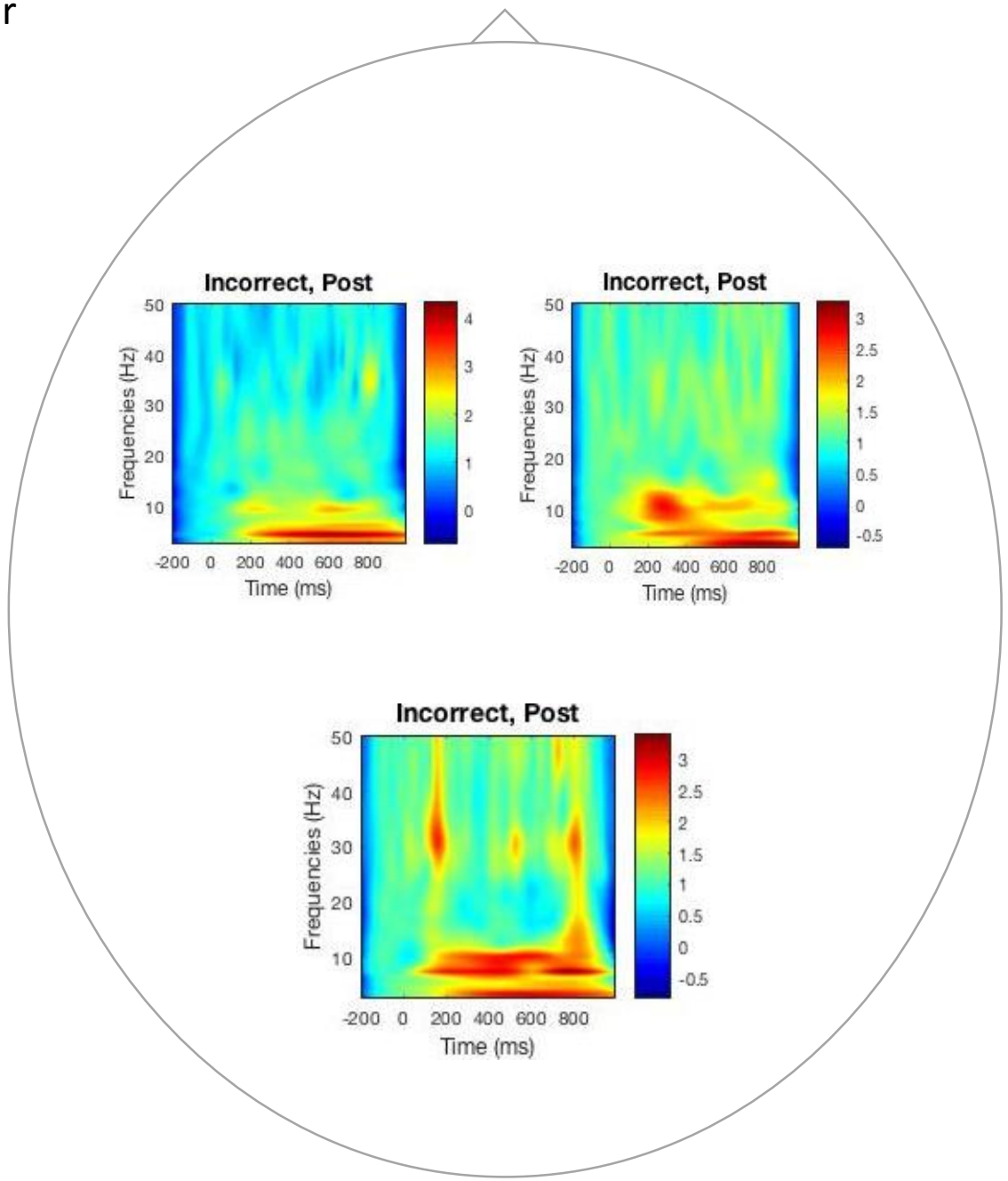

Incorrect, Post
Frequencies (Hz)
50
40
30
20
10
-200 0 200 400 600 800
Time (ms)
3
2
1
0


Incorrect, Post
Frequencies (Hz)
50
40
30
20
10
-200 0 200 400 600 800
Time (ms)
3
2.5
2
1.5
1
0.5
0
-0.5

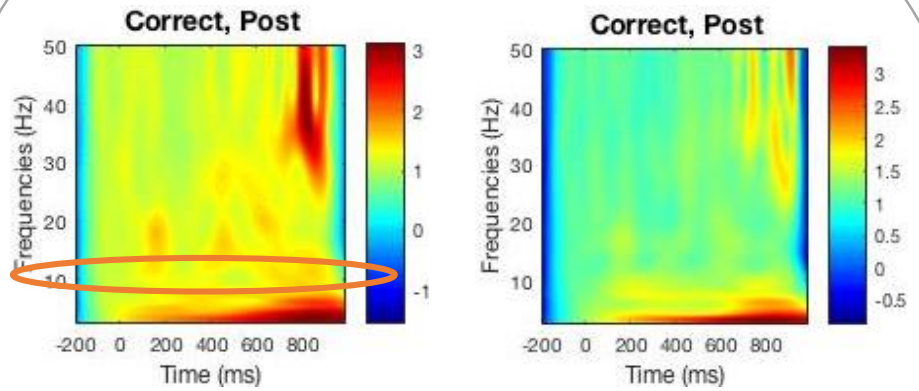

Incorrect, Post
Frequencies (Hz)
50
40
30
20
-200 0 200 400 600 800
Time (ms)
3
2
1
0

3 Mirror

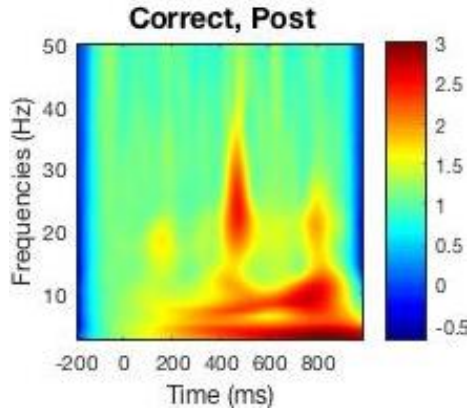

Correct, Post
Frequencies (Hz)
Time (ms)
Correct, Post
Frequencies (Hz)
Time (ms)
Correct, Post
Frequencies (Hz)
Time (ms)

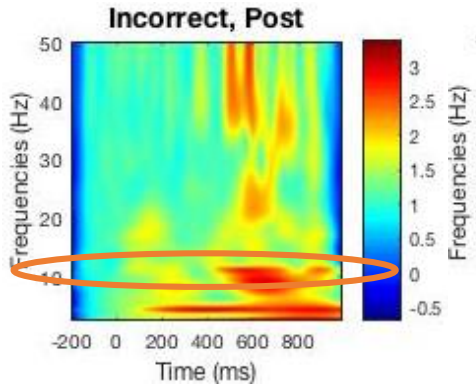

Incorrect, Post
Frequencies (Hz)
Time (ms)
Incorrect, Post
Frequencies (Hz)
Time (ms)
Incorrect, Post
Frequencies (Hz)
Time (ms)

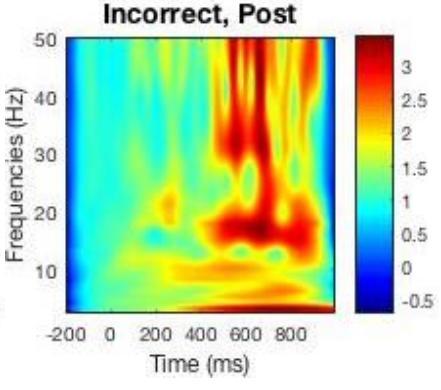
5 Mirrors

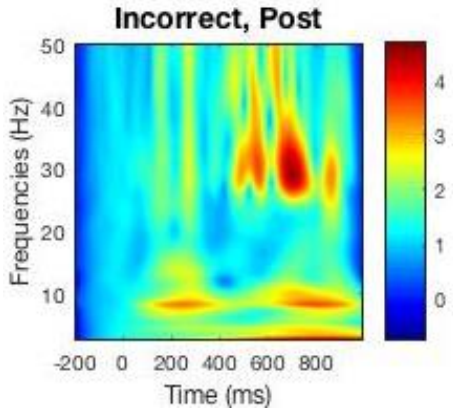

Correct, Post
Frequencies (Hz)
Time (ms)

Correct, Post
Frequencies (Hz)
Time (ms)


Correct, Post
Frequencies (Hz)
Time (ms)


Incorrect, Post
Frequencies (Hz)
Time (ms)


Incorrect, Post
Frequencies (Hz)
Time (ms)


Incorrect, Post
Frequencies (Hz)
Time (ms)

Discussion

- JTF demonstrate reduction in brain activation in fronto-parietal network after learning (Soltanlou et al., 2018)
- Alpha differences in Pre and Post 1 & 5 Mirror conditions at Superior Frontal Sulcus during Incorrect.
    1. Attending to a visuospatial reasoning task at SFG
    2. Alpha is not suppressed in the incorrect trials. Participants had difficult with cognitive control, or engagement in the task.
    3. Alpha Decrease is associated with Retrieval Strategies (Pfurtscheller, 2001)
    4. In order to correctly engage in spatial reasoning, Frontal Sulcus would need to work to suppress alpha.

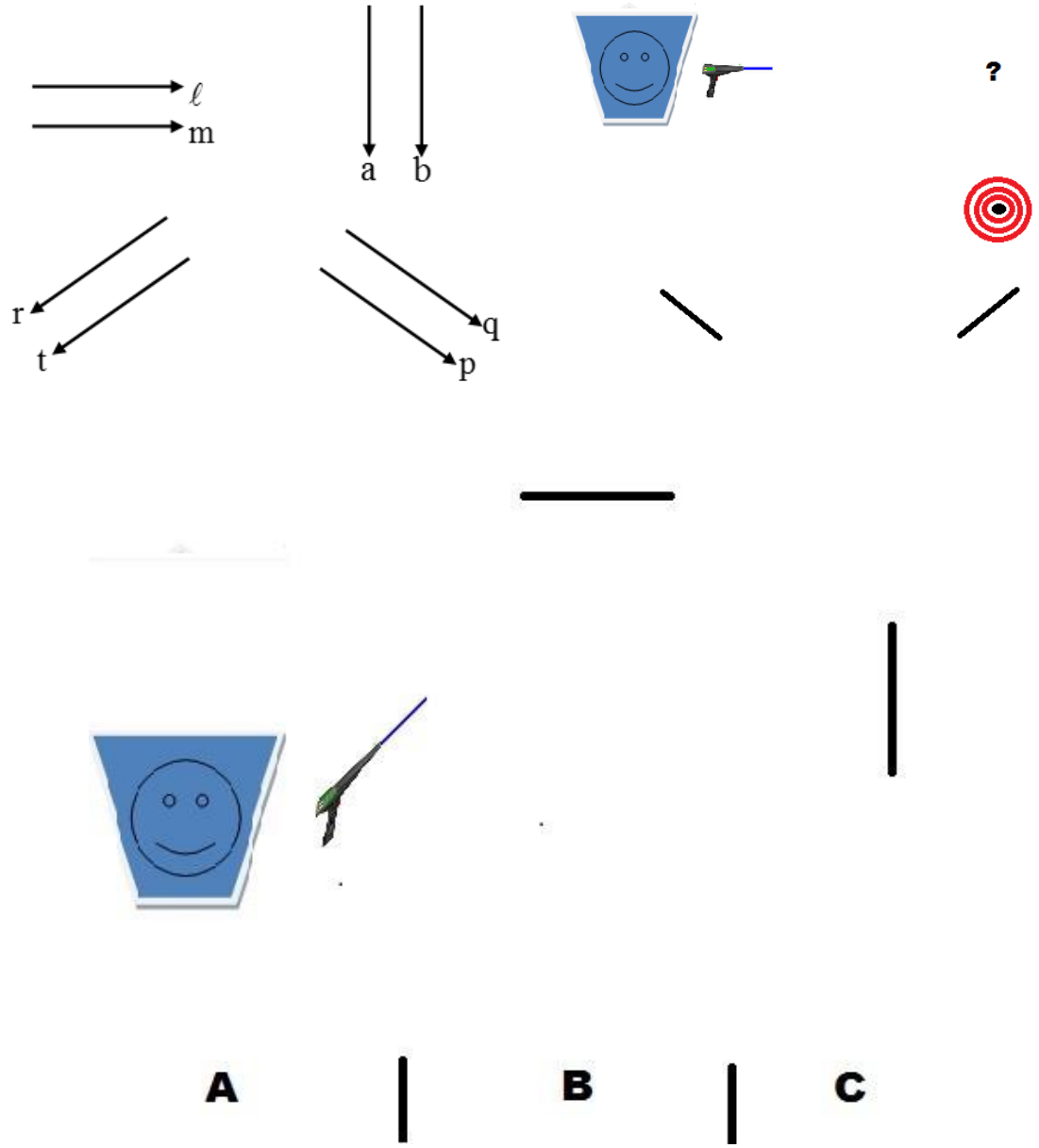
- Three mirror Gamma bursts in Prefrontal Cortex
    - VSWM task

Conclusions

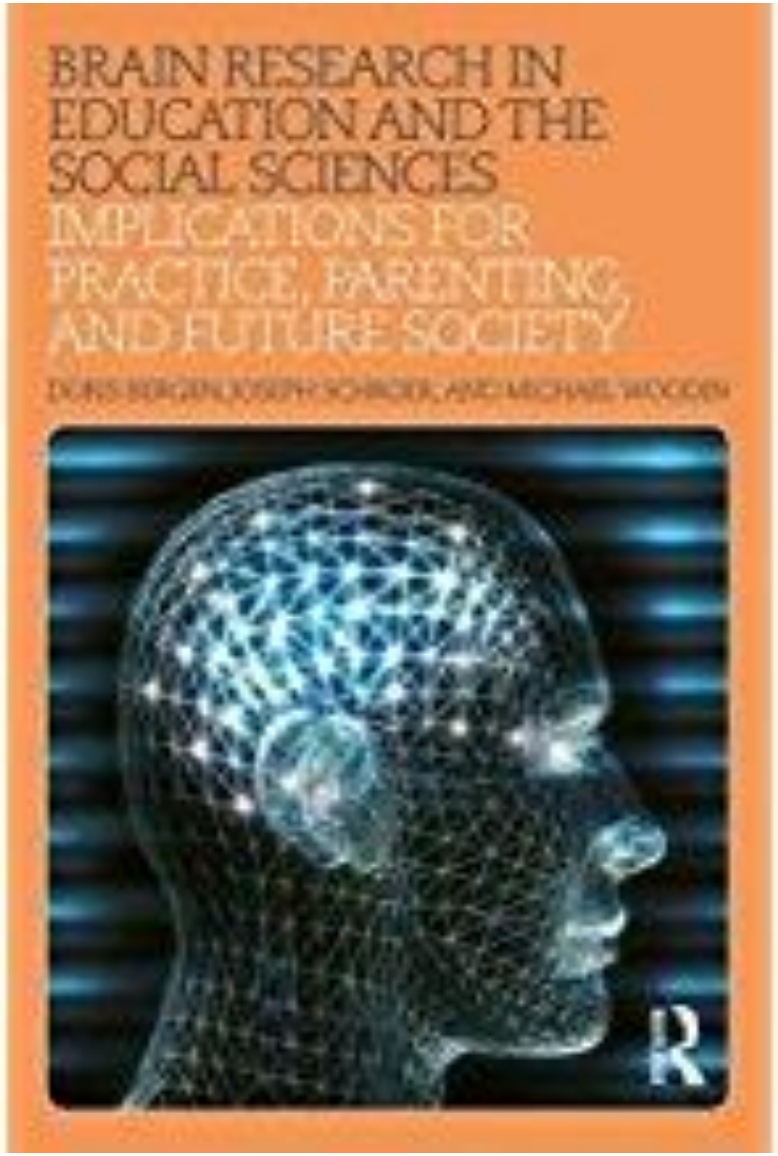
- Children Ages 6-12 can learn spatial reasoning through videogames
  - 6-7 year-olds have difficulties with individual differences
  - Developmental, Gender, & Individual Differences in development in Spatial Concept Learning
- The more difficult the spatial reasoning task, the higher the cognitive load in the Parietal Area (Overall ERPs).
- Prefrontal Cortex important for VSWM for Attention & Reasoning
  - Superior Frontal Sulcus is crucial for Spatial Reasoning Concept Learning- VSWM Retrieval for children

Future Work

- Replicate & Combine for Power.
- Eye-Tracking
- Novel Transfer Tasks
- Virtual vs Real World



Thank you.



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P300

P3 most active in parietal lobe during mental rotation (Wijers et. al., 1989; Heil et. al., 2002, Milivojevic, et. al., 2009)

- ✓ **Amplitude modulation as a correlate of mental rotation**

- Heath et.al., (2015) did not find increase in amplitude
  - ✓ Qualitatively different task of reaching