The Neurobiology of Mother-Infant Attachment

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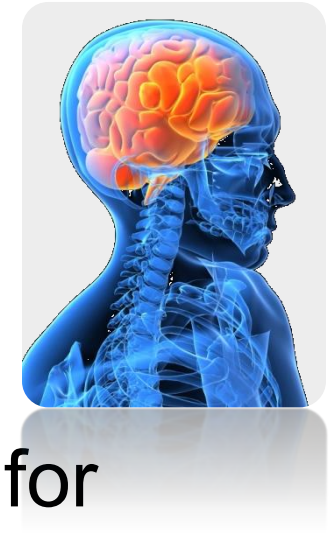
Why study the maternal brain?



- Early maternal care is critical for infant development:
  - Cognitive development
  - Stress reactivity in adulthood
  - Maternal behavior of female offspring
  - Attachment security
- Biology helps us to understand psychology—and vice versa!
- Future potential for pharmacotherapy

Neuroendocrine Systems Important in Maternal Behavior

1. Dopamine
   - Nucleus accumbens shell DA important in rat maternal behavior and released during mother-pup interaction
   - Prediction of temporal differences/errors
   - Important factor in cognitive development

2. Oxytocin
   - Central neuromodulator critical for the onset of maternal behavior, and
   - Social memory;
   - Anxiolytic properties

What stimulates the maternal brain?

- Sensory input
  - Olfactory – e.g. infant/pup odors
  - Somatosensory – e.g. touch, nursing, licking and grooming
  - Auditory – e.g. infant cry
  - Visual – e.g. infant facial cues

Questions:

- What maternal brain and endocrine systems are activated in response to infant cues?
- Are there individual differences in how mothers respond to these cues?

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Model: Maternal Brain Responses

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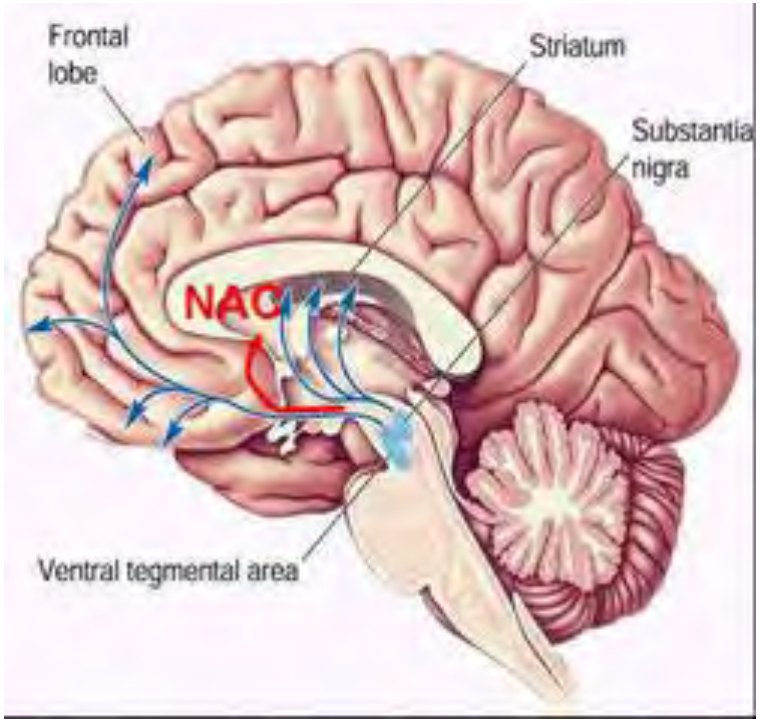
Mesocorticolimbic Dopamine Pathway: "Reward"

Nigrostriatal Dopamine Pathway: "Action Contingencies"

SENSORY INPUT
(e.g. infant face cues)



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(e.g. caregiving behavior)

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FOREBRAIN "Frontal Cortex"

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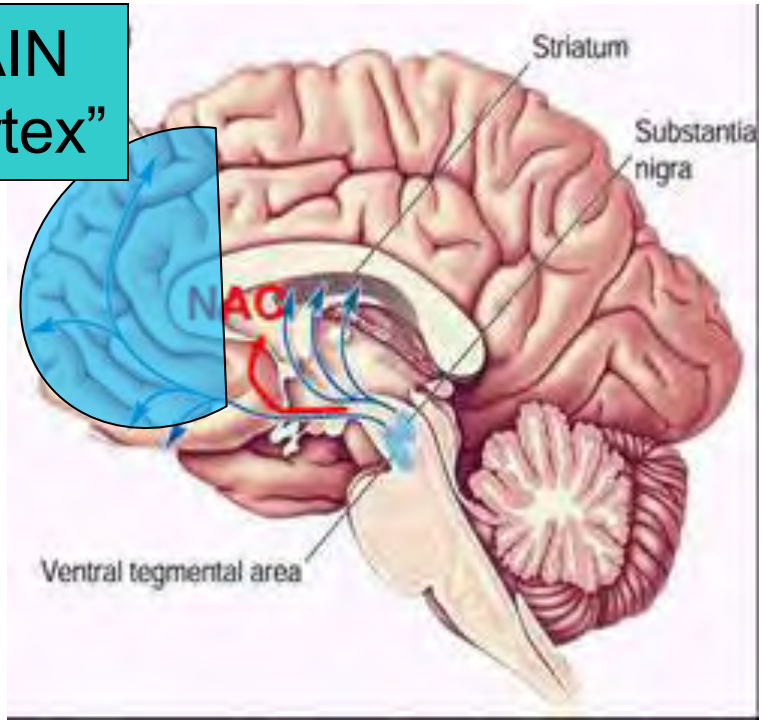

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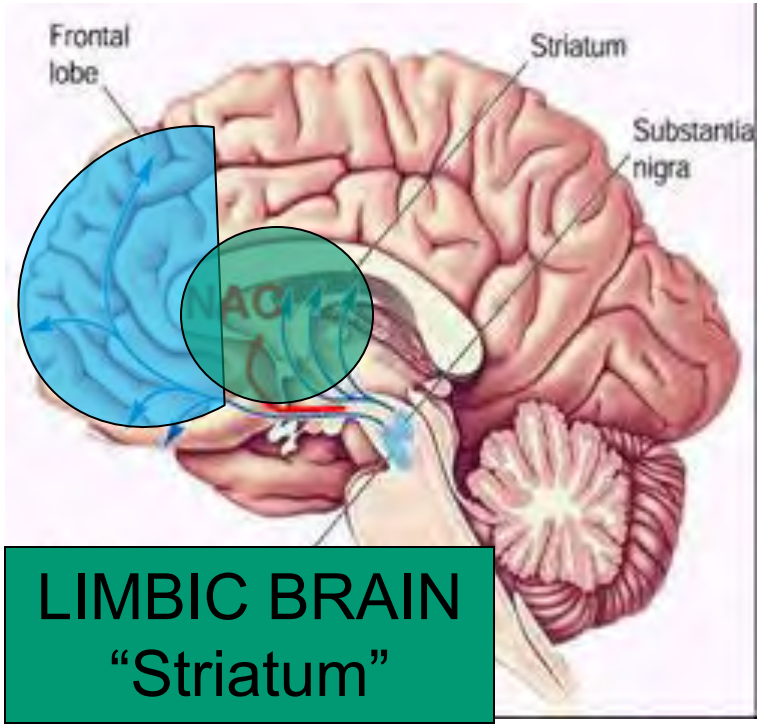

LIMBIC BRAIN
"Striatum"

MOTOR OUTPUT
(e.g. caregiving behavior)

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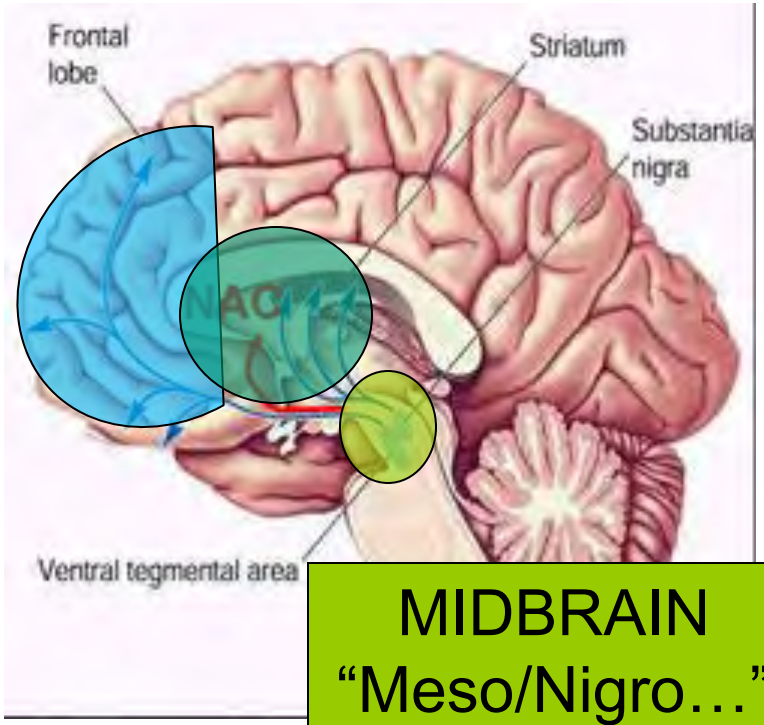

MIDBRAIN
"Meso/Nigro…"

MOTOR OUTPUT
(e.g. caregiving behavior)

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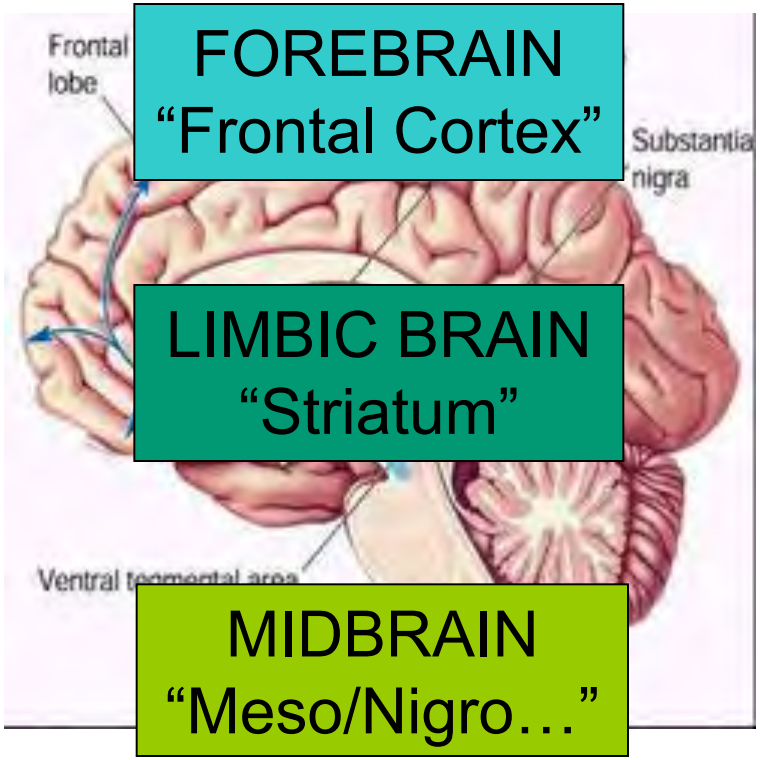

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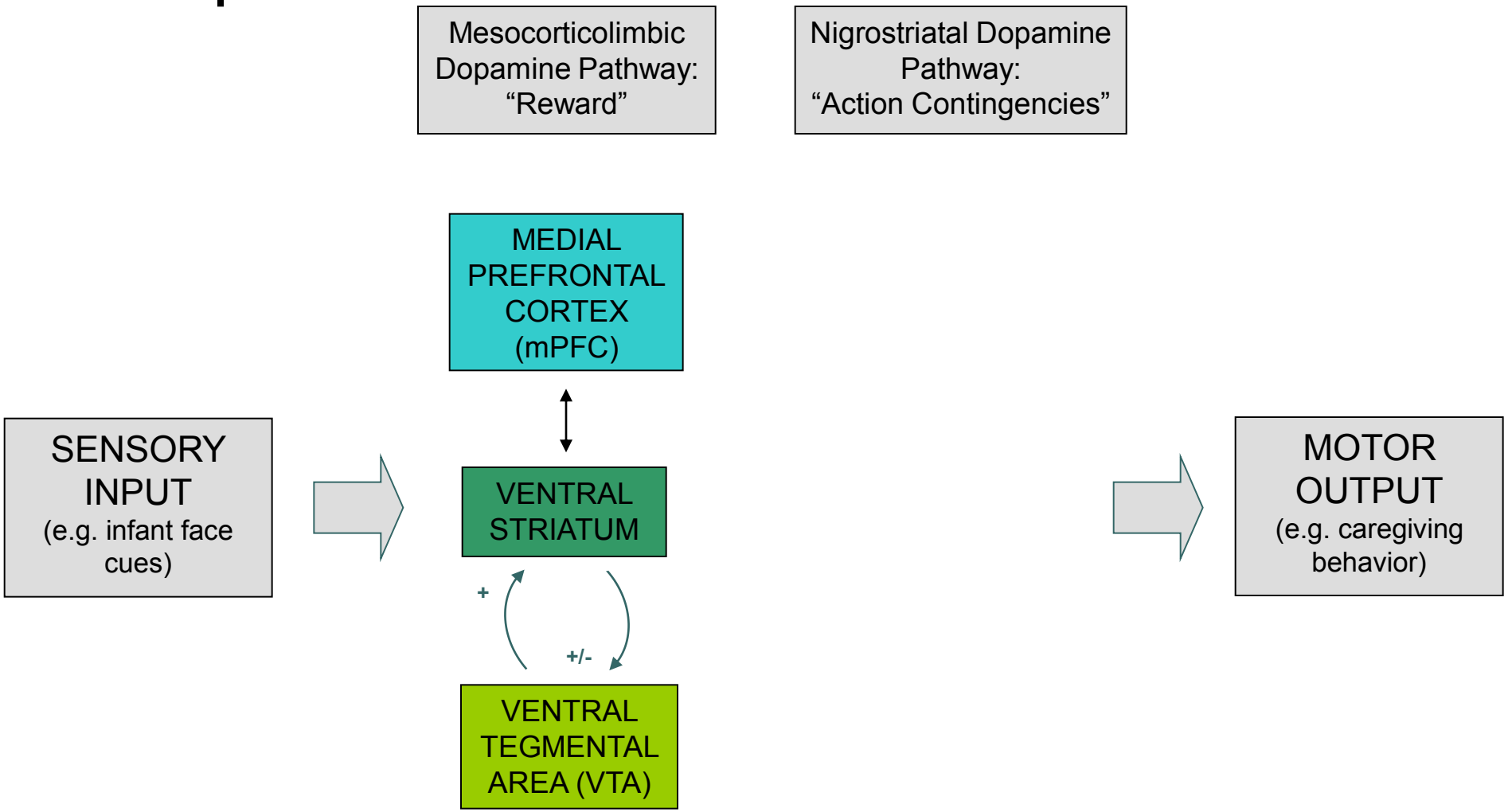

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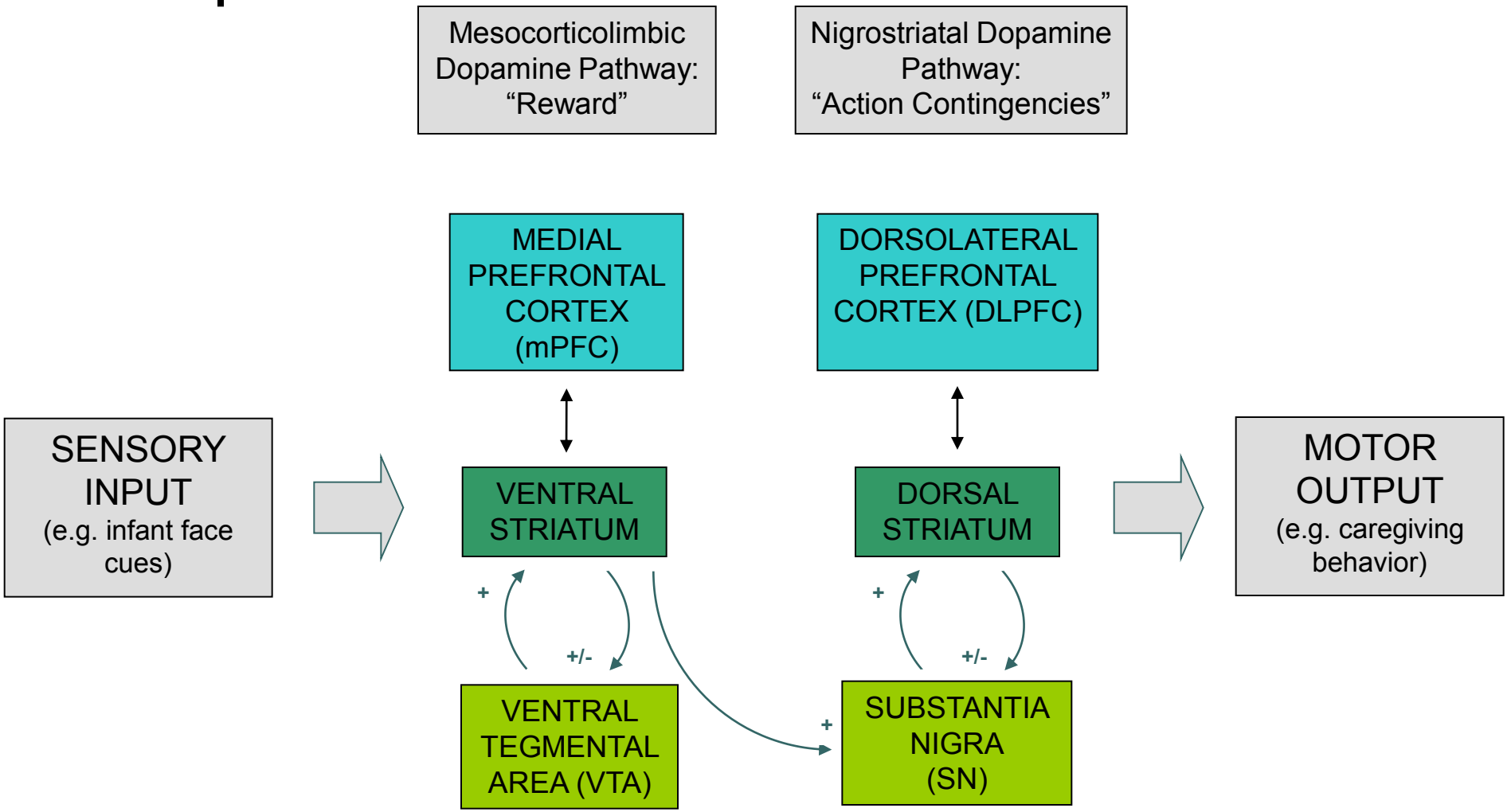

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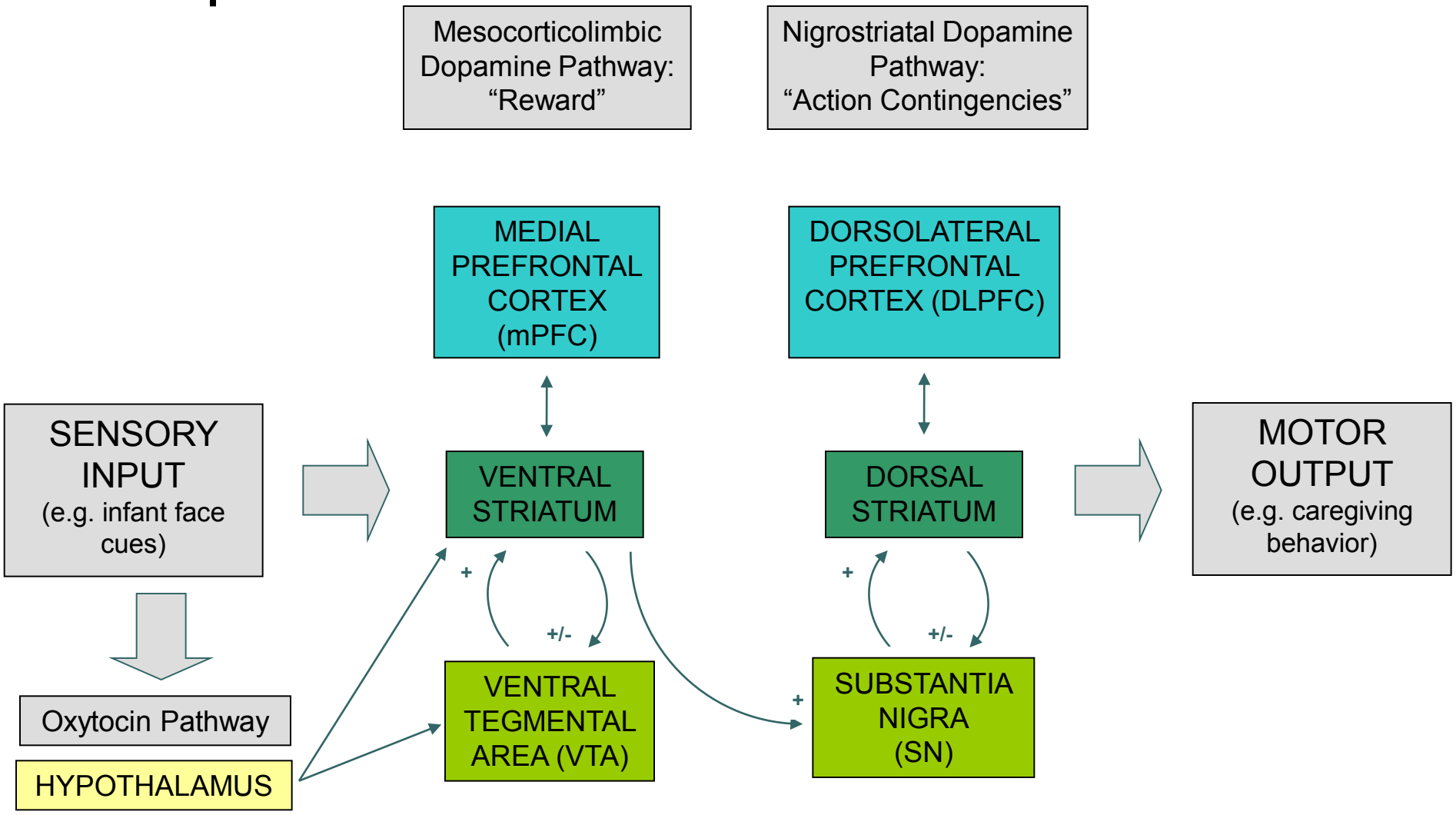
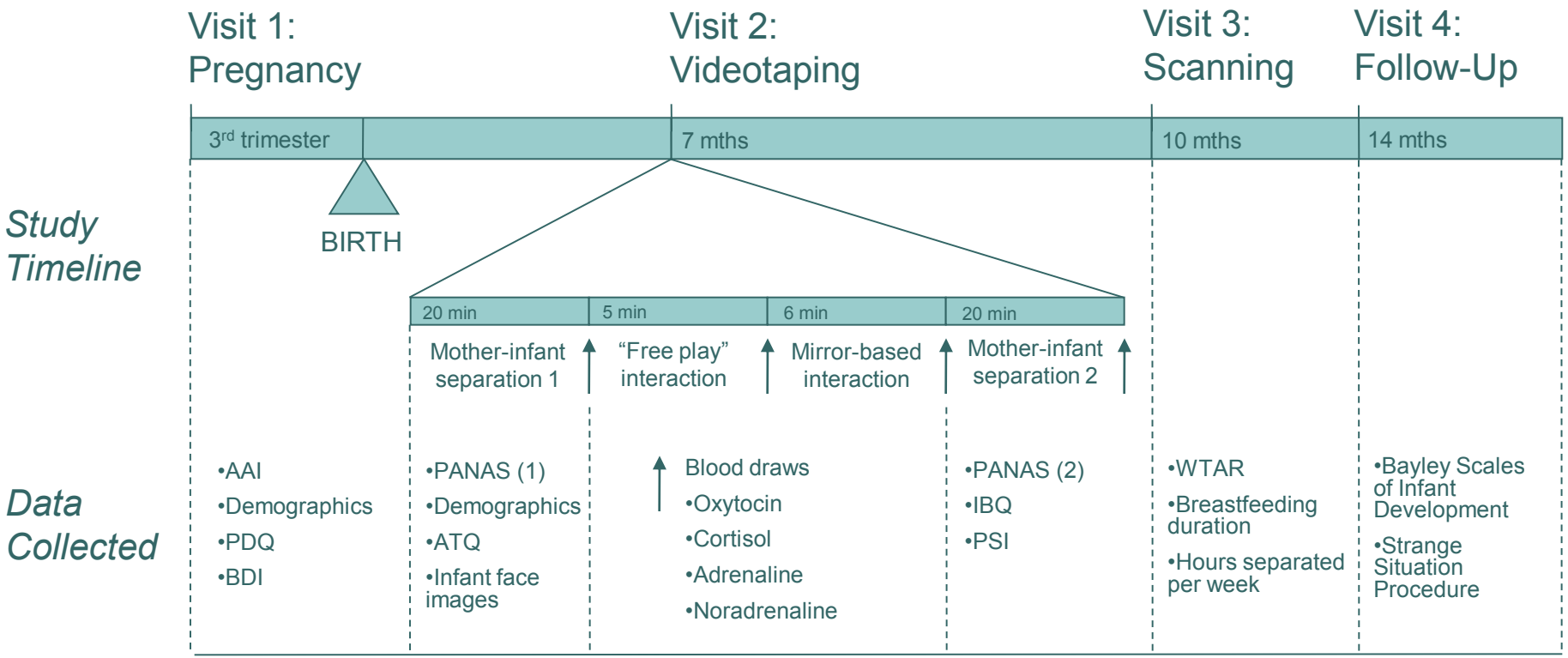
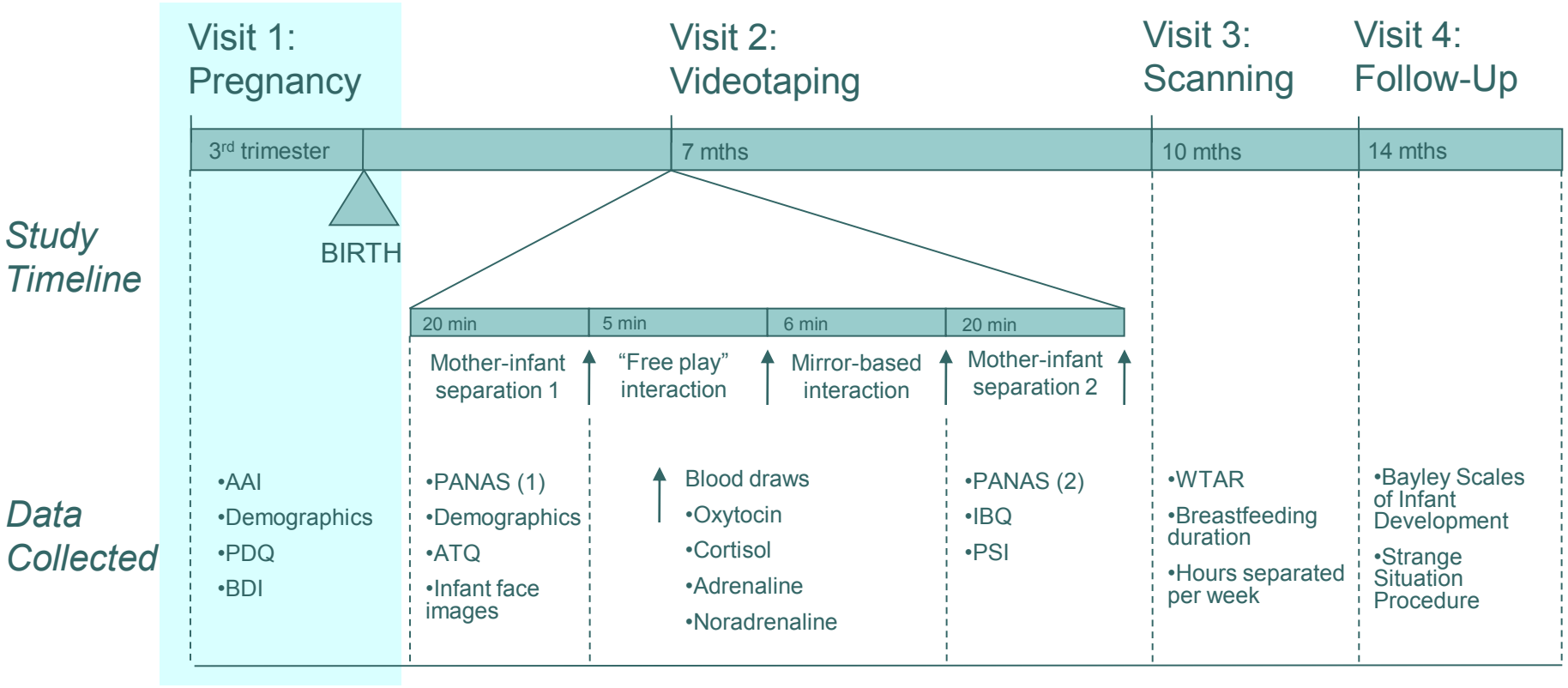


Study Outline



Visit 1: Pregnancy



Visit 2: Videotaping

Study Timeline

Data Collected

Visit 1: Pregnancy

- 3rd trimester
- BIRTH

Visit 2: Videotaping

- 7 mths
- 20 min: Mother-infant separation 1
- 5 min: "Free play" interaction
- 6 min: Mirror-based interaction
- 20 min: Mother-infant separation 2

Visit 3: Scanning

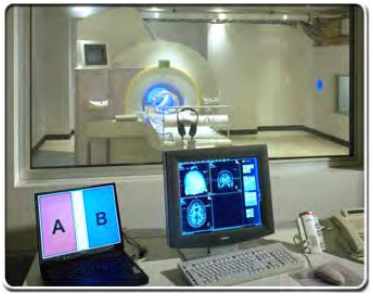
- 10 mths

Visit 4: Follow-Up

- 14 mths

Visit 1: Pregnancy	Visit 2: Videotaping	Visit 3: Scanning	Visit 4: Follow-Up
•AAI •Demographics •PDQ •BDI	•PANAS (1) •Demographics •ATQ •Infant face images Blood draws •Oxytocin •Cortisol •Adrenaline •Noradrenaline •PANAS (2) •IBQ •PSI	•WTAR •Breastfeeding duration •Hours separated per week	•Bayley Scales of Infant Development •Strange Situation Procedure

Visit 3: Scanning



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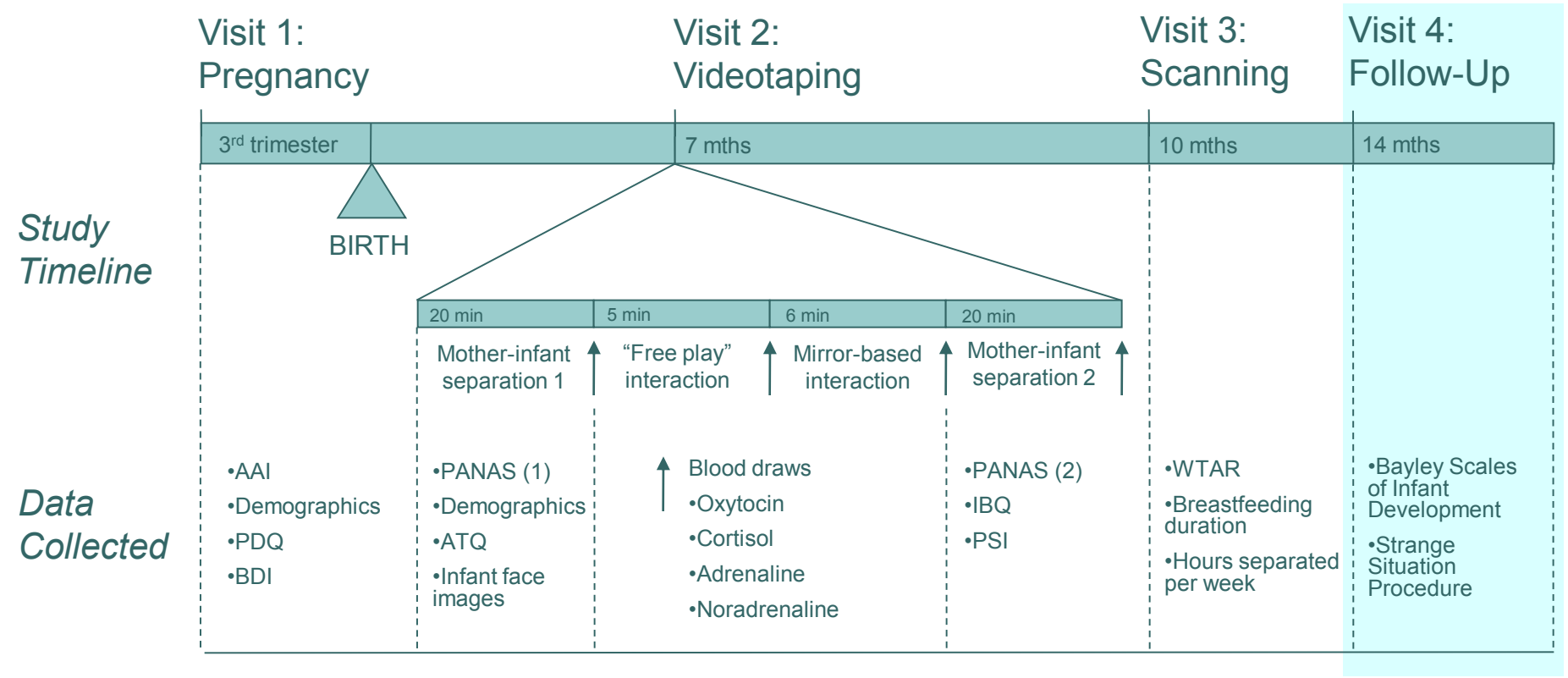
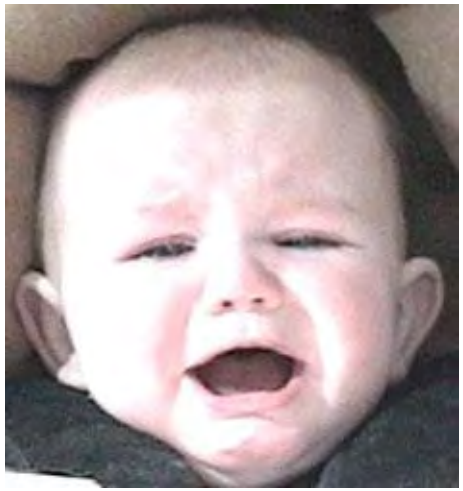
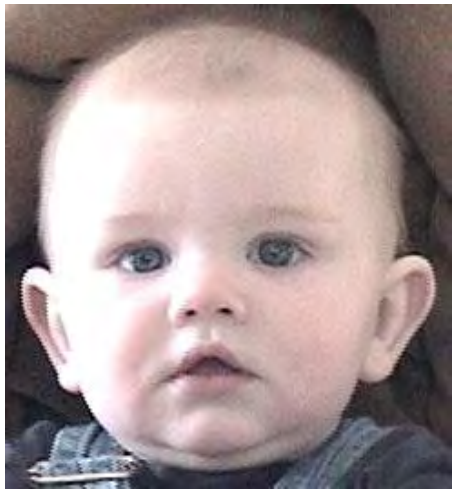


Three Affective States

Crying

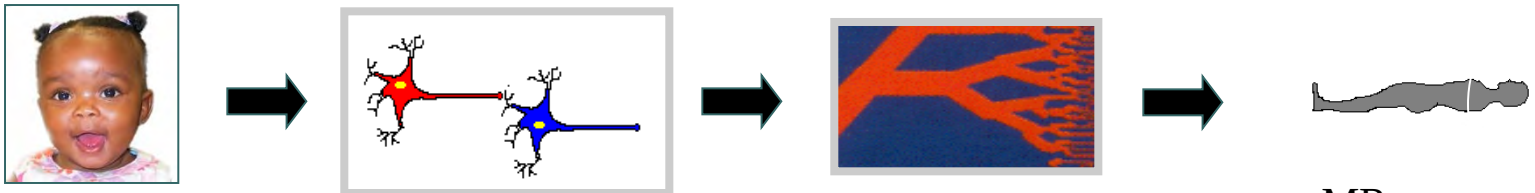


Neutral



Smiling

The Hemodynamic Response



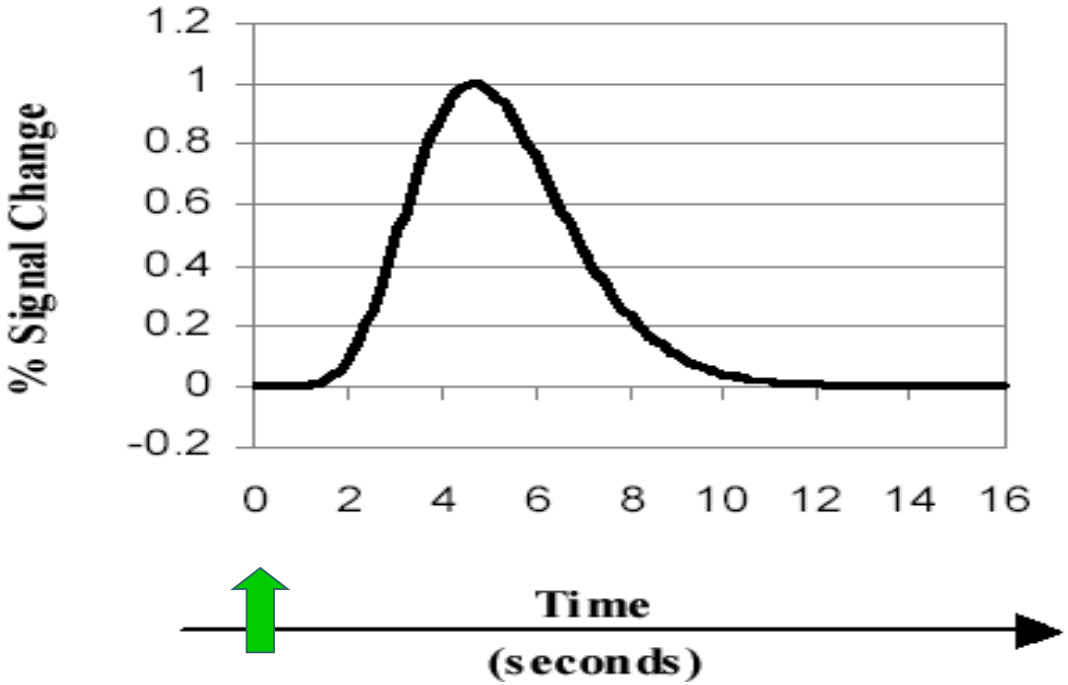
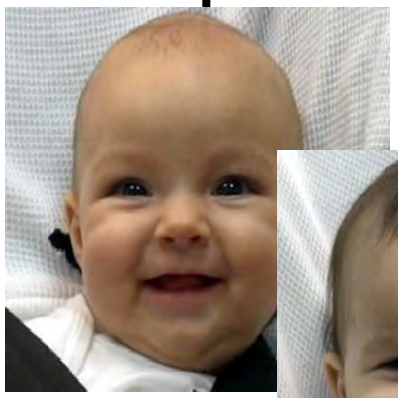
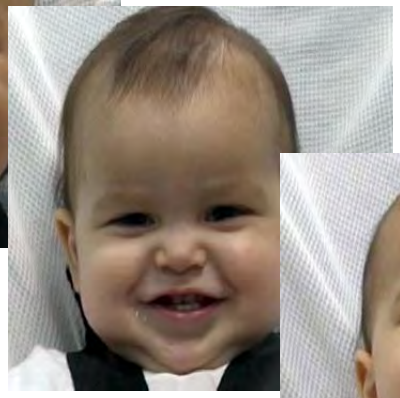


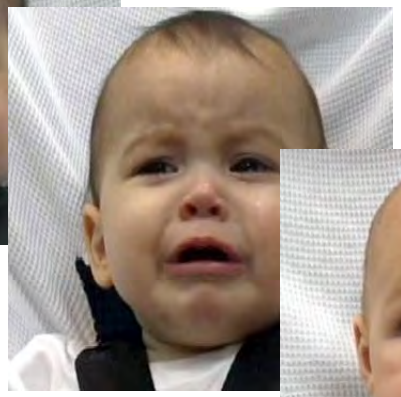
Figure adapted from Chein & Schneider



Own:
Happy
(OH)

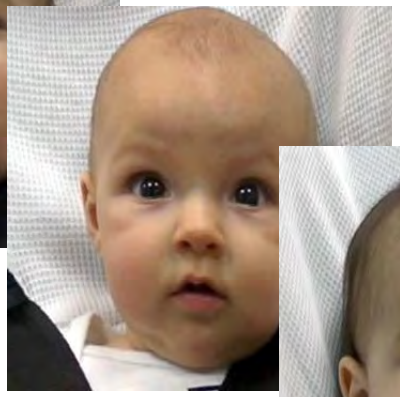


Unknown:
Happy
(UH)

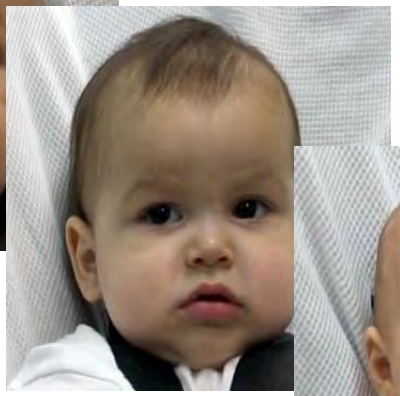


Unknown:
Sad
(US)

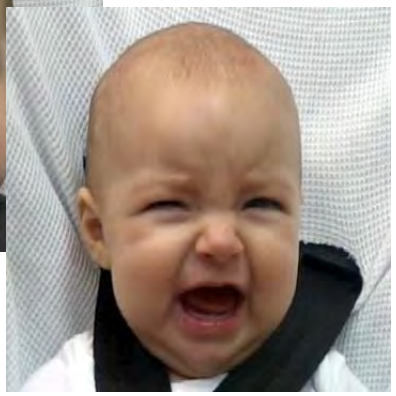
2–6 sec random
inter-stimulus
interval



Own:
Neutral
(ON)



Unknown:
Neutral
(UN)



Own:
Sad
(OS)

STIMULUS TYPES		IDENTITY	
		Own Infant	Unknown Infant
AFFECT	Happy	OH	UH
	Neutral	ON	UN
	Sad	OS	US

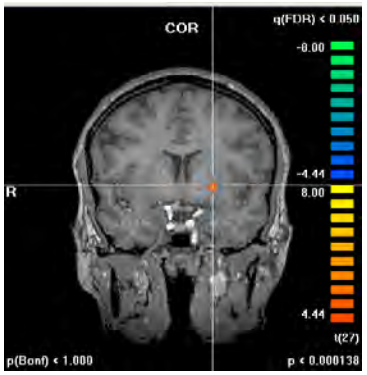
Scanning and analysis

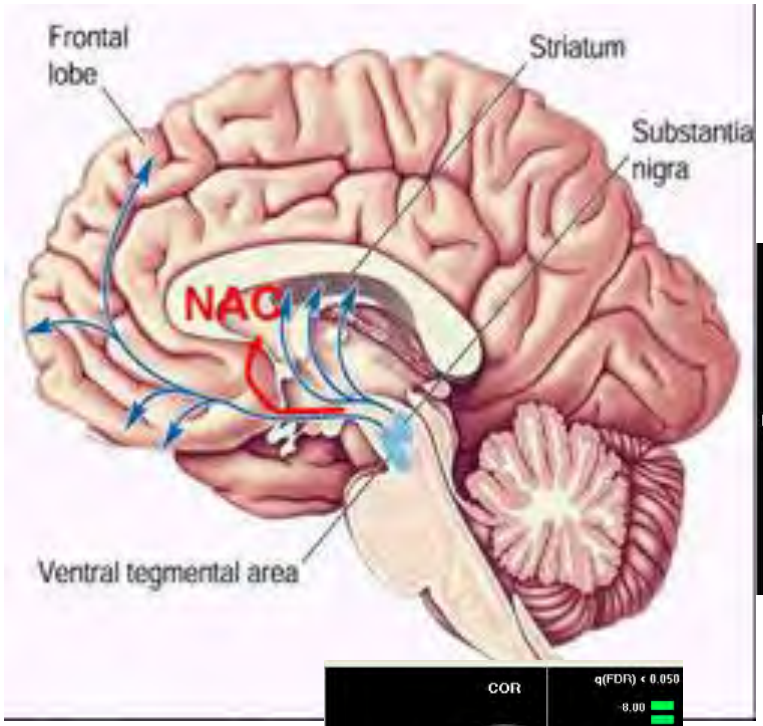
- Event related paradigm
- 2 runs with 60 unique face images per run
- Gradient recalled echo planar imaging using Siemens 3T scanner
- Imaging data preprocessed and analyzed in BrainVoyager QX, version 1.8.6.
- False discovery rate (FDR) correction for multiple comparisons ($q<0.05$).
- Whole brain analysis using GLM; group effects evaluated using a random effects analysis
- ANOVA used to compare attachment groups in fMRI and OT response.

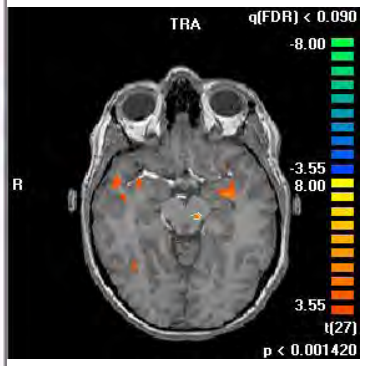
Initial Findings

Cingulate Cortex

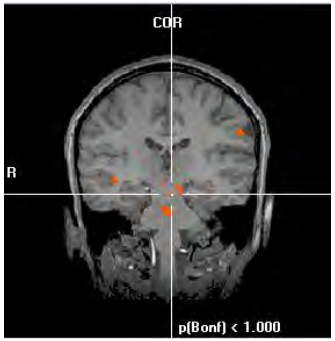
Ventral striatum



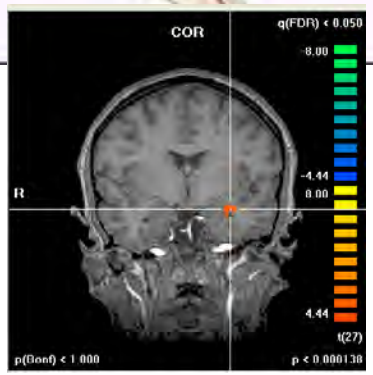




Substantia nigra



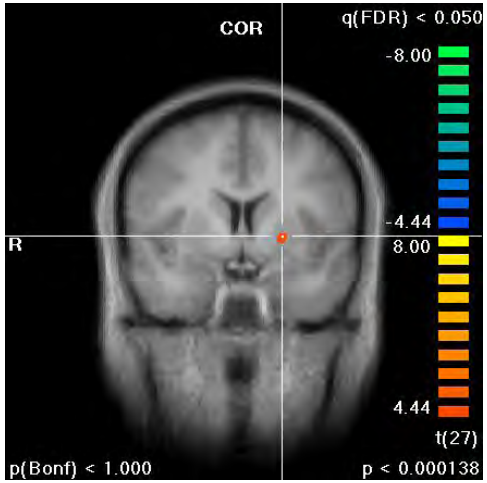
VTA

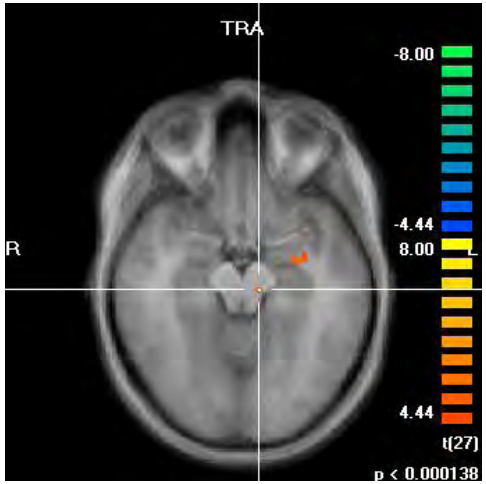


Amygdala

n=28, p<0.001(uncorr.)

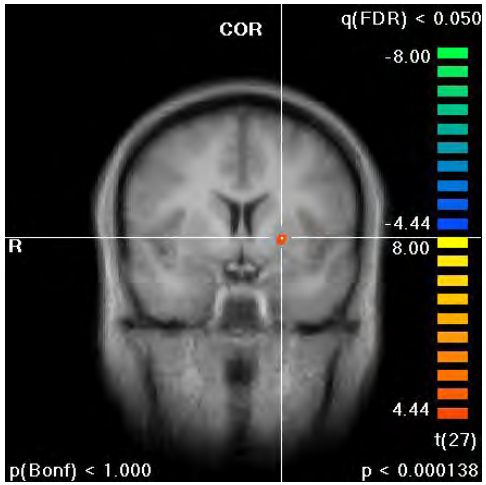
A. Dorsal putamen

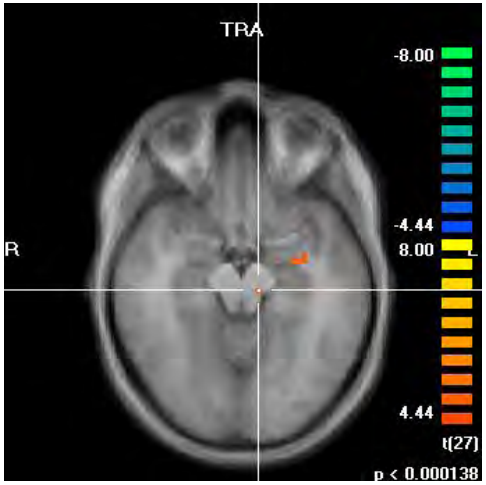




B. Substantia nigra

A. Dorsal putamen





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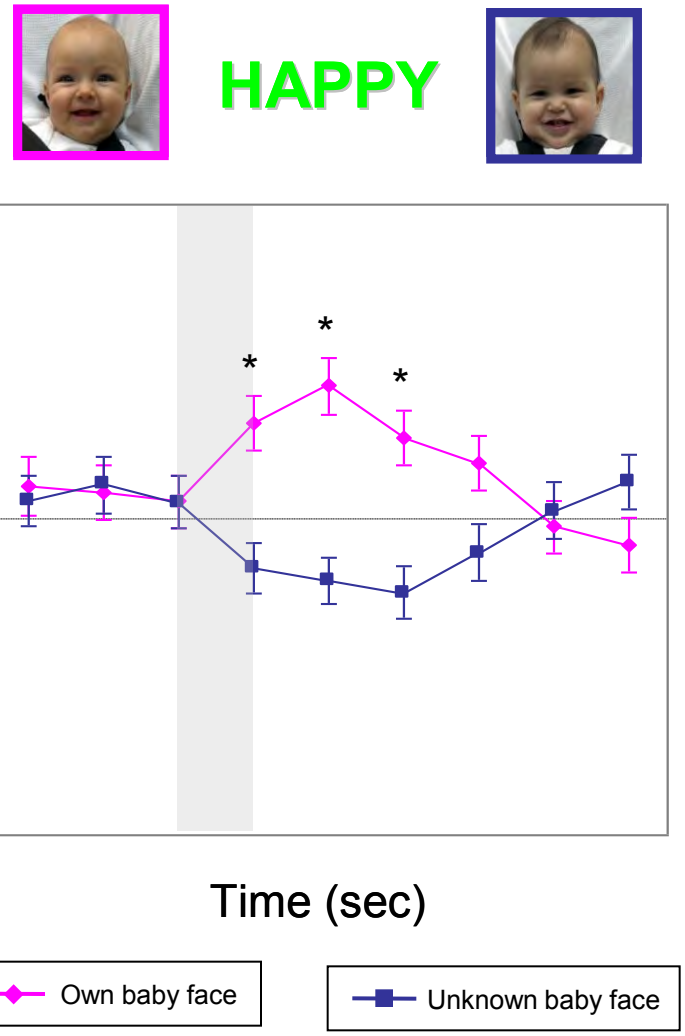

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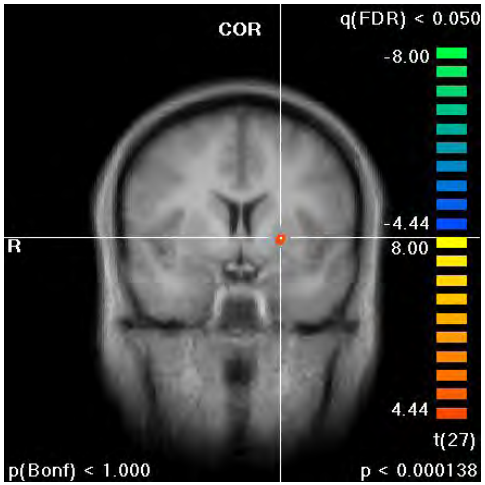

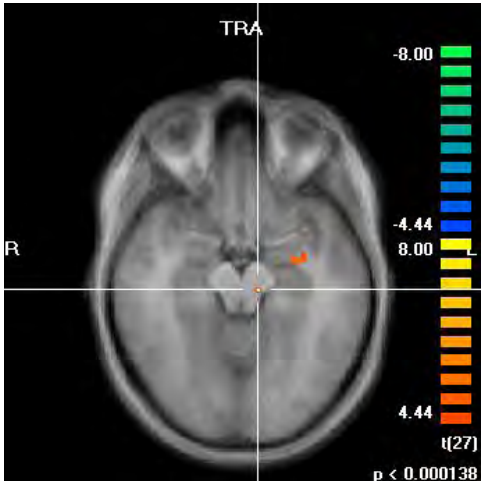

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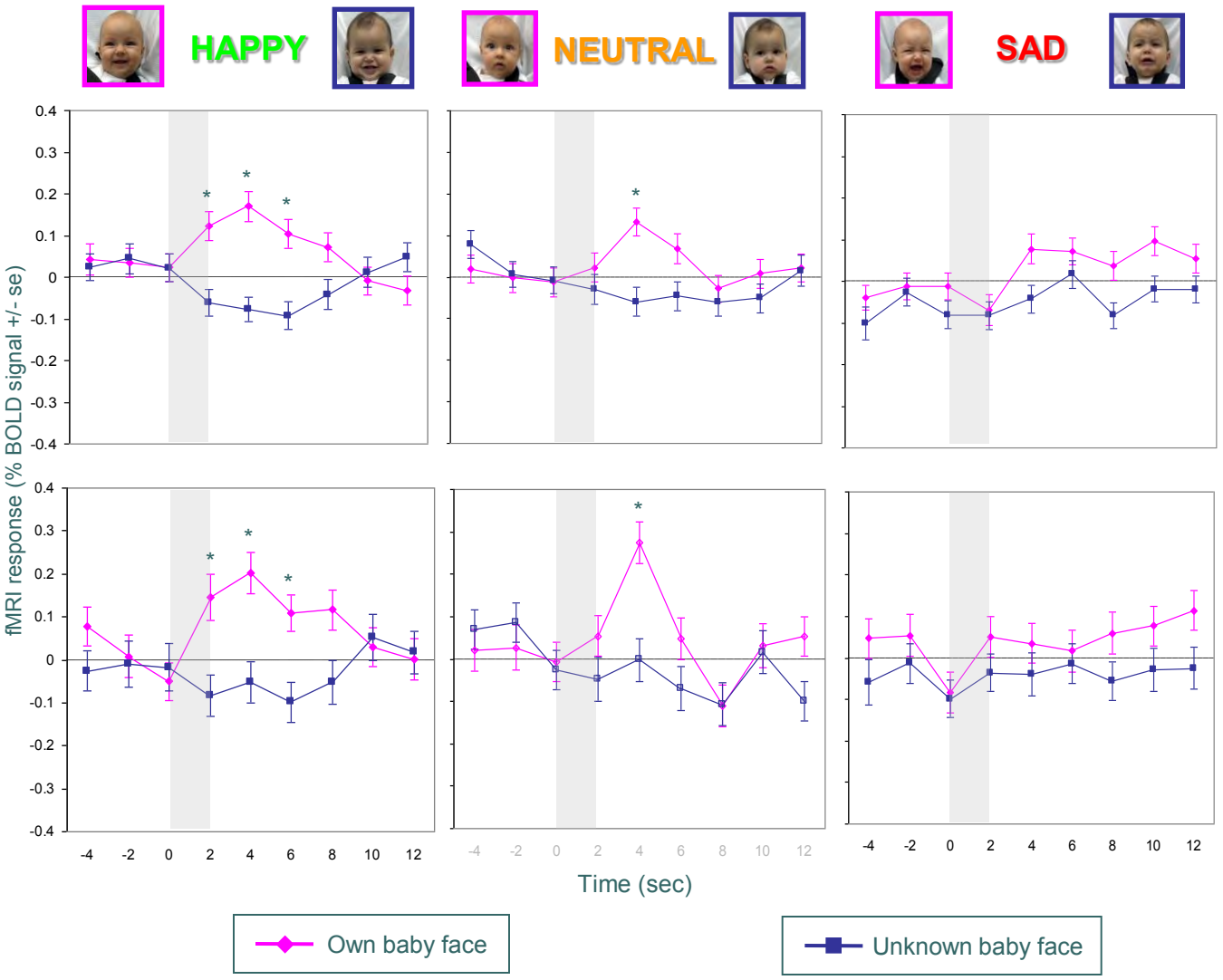

Summary

- Happy baby faces preferentially activate dopamine-associated reward related brain regions
  - Dorsal striatum
  - Substantia nigra
- No response difference for own vs. unknown SAD faces

Questions:

- What maternal brain and endocrine systems are activated in response to infant cues?
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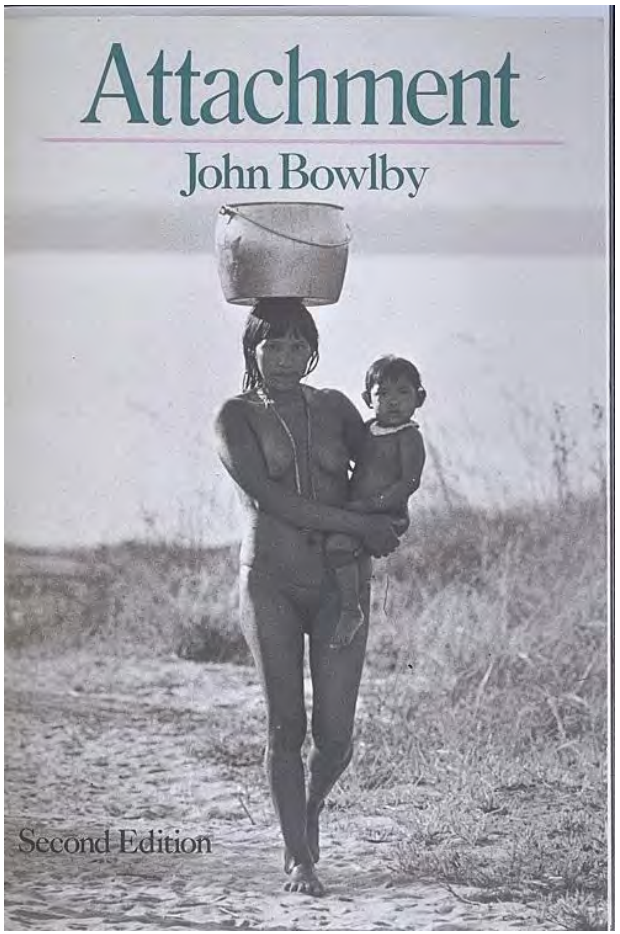
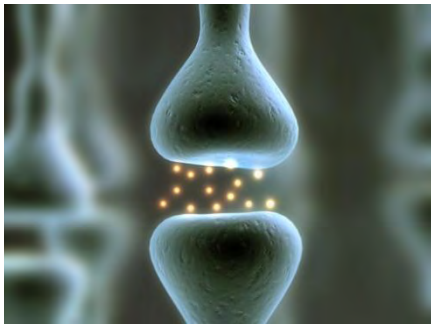
Attachment Theory

- Originally formulated by John Bowlby in 1969
- Innate biological system to ensure protection and reproduction
- Individual differences in attachment “security” are associated with maternal care and infant social/emotional development



Human and Animal Models of Maternal Behavior



- Areas of known significance
  - Dopamine “reward” pathways
    - Ventral striatum
    - Medial prefrontal cortex
  - Oxytocin “affiliation” pathways
    - Pituitary gland
    - Hypothalamus (MPOA, PVN)
- The development of these systems appears to be strongly influenced by early maternal care
- How are these brain regions associated with differences in adult attachment?

Oxytocin and maternal caregiving

- Oxytocin is a peripheral hormone important in childbirth and lactation
- Breastfeeding/suckling stimulates its production
- It also has important central effects in the brain to help prepare for long-term child rearing
- “Calm and connection” effect

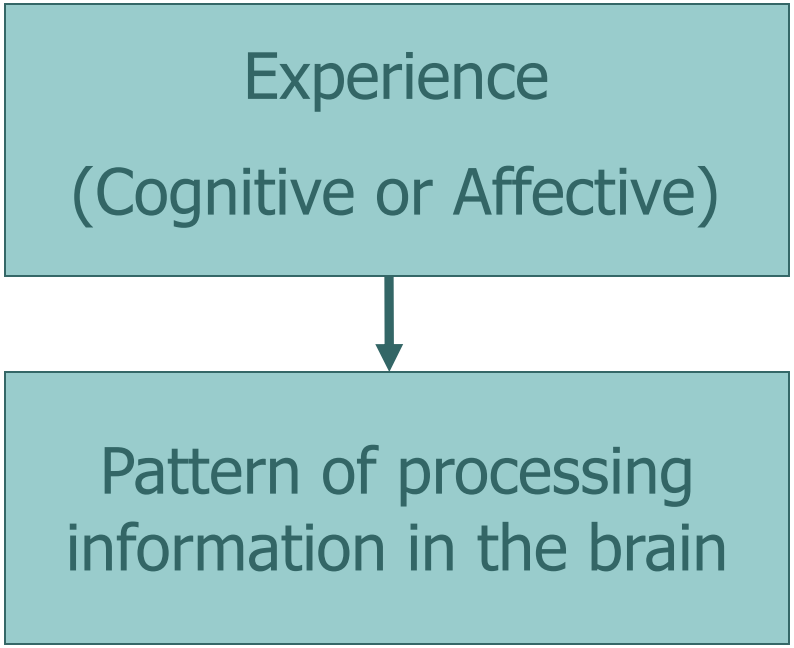
Oxytocin and maternal caregiving

- In animal models of maternal care, oxytocin is critical for the initiation of maternal care
- In ewes, oxytocin results in selective bonding with the lamb
- Oxytocin neurons may also connect with the brain's dopamine "reward" system, resulting in changes in "long-term conditioned preferences"

Oxytocin and maternal caregiving

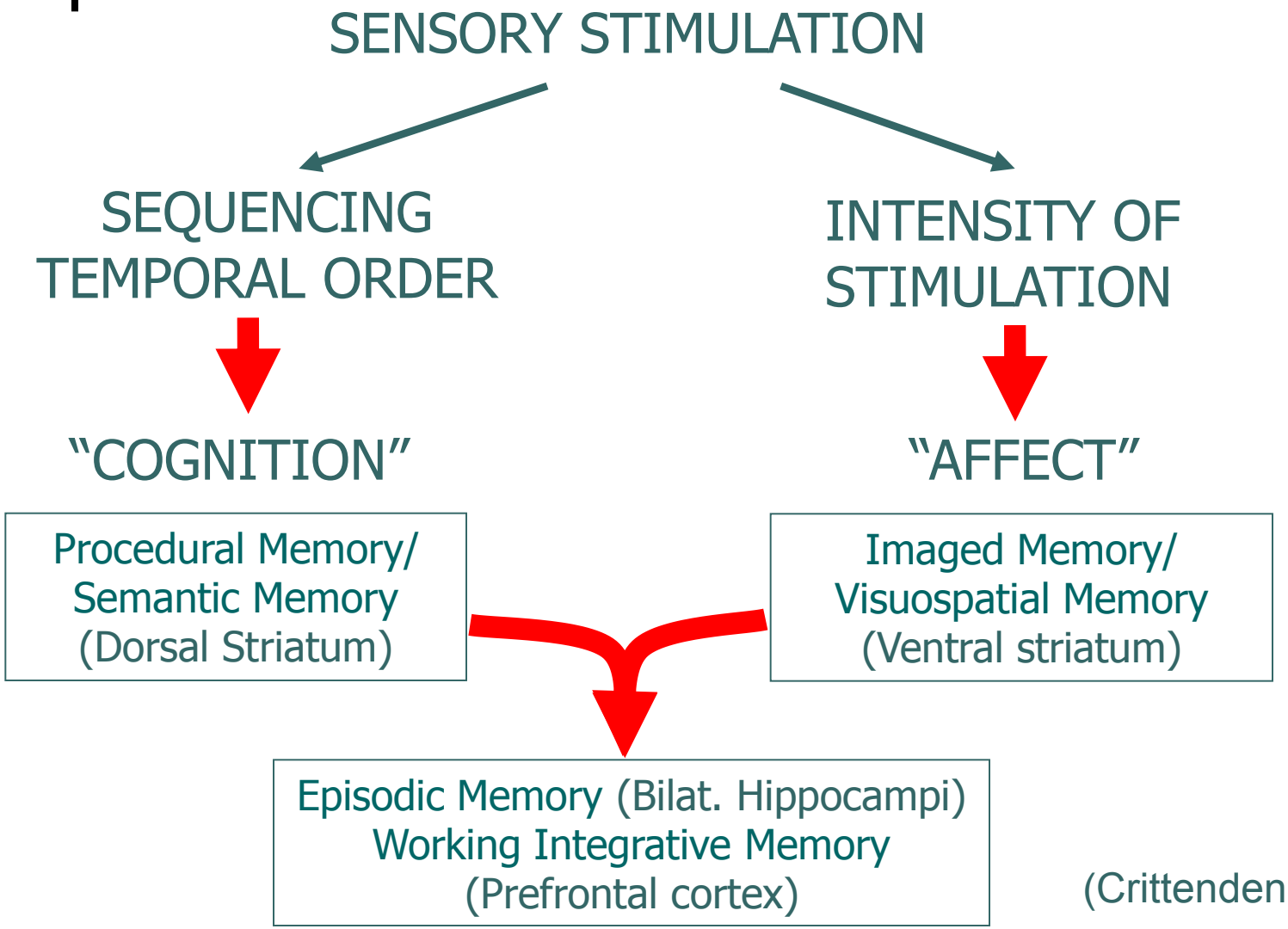
- In human studies, intranasal oxytocin results in:
  - Increased trust
  - Reduced anxiety
  - Improved recognition of facial affect
  - Decreased fear responses
  - Increased eye gaze
- Oxytocin may stimulate dopamine reward pathway in the brain

Attachment Theory – Memory and Learning



(Crittenden, 2004)

Attachment and Memory Systems

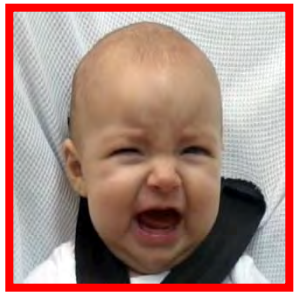


(Crittenden, 2004)

Group Comparisons

- Comparison of 15 “secure” mothers and 15 “insecure/dismissing”
- No significant group differences were seen, with respect to:
  - Maternal SES, race, education or IQ
  - Self-reported parenting stress
  - Pre- or post-natal depression or psychopathology risk
  - Mother or infant temperament
  - Infant development at 14 months
  - Breastfeeding duration
- Insecure/dismissing mothers separated from their infant for more hours per week
  - 67% vs. 27% separated for >20 hours per week

Secure vs. Insecure/Dismissing

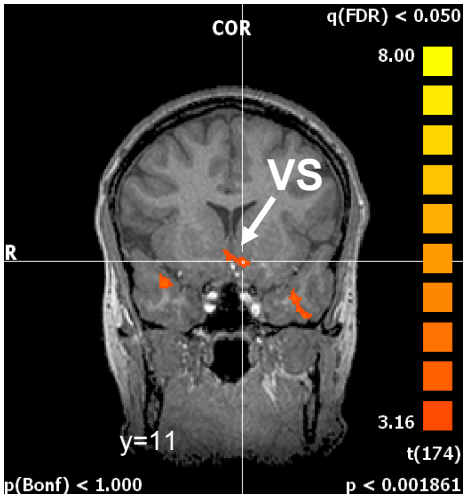


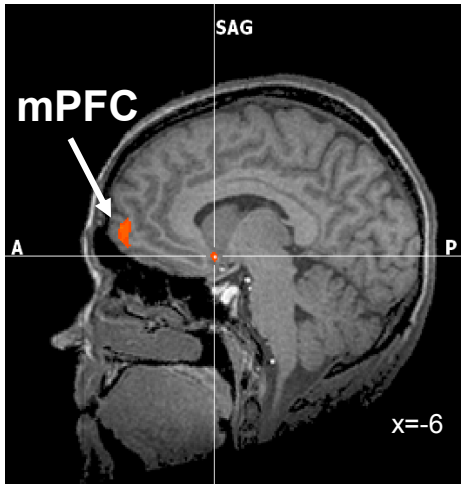
SECURE	INSECURE / DISMISSING
∘ Medial PFC ∘ Orbitofrontal cortex ∘ Ventral striatum	∘ Dorsolateral PFC

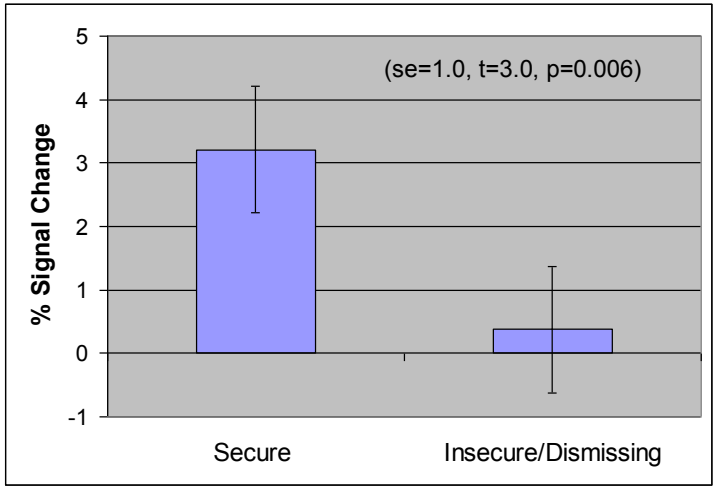
Own Happy Faces: Secure vs. Insecure Attachment

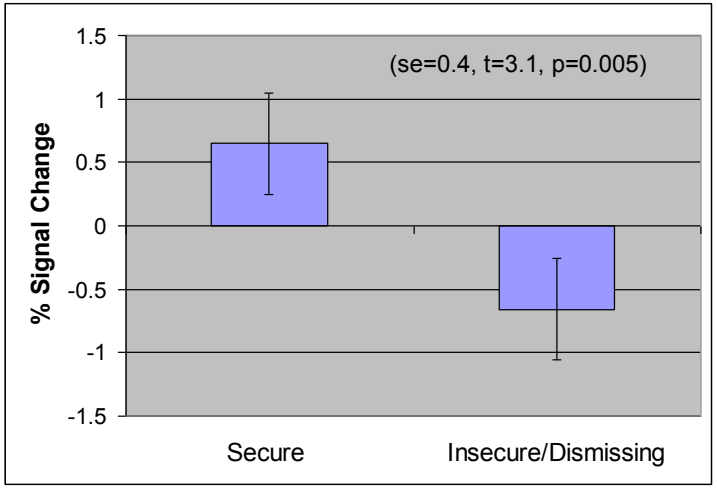
Bilateral Ventral Striatum

R Medial PFC

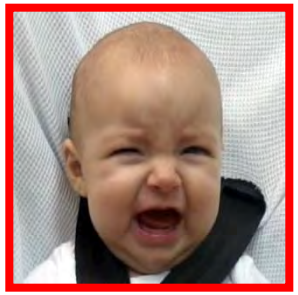








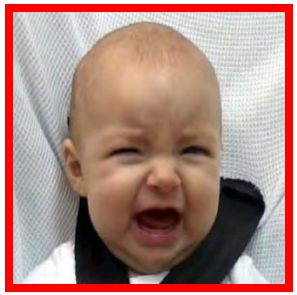
Secure vs. Insecure/Dismissing

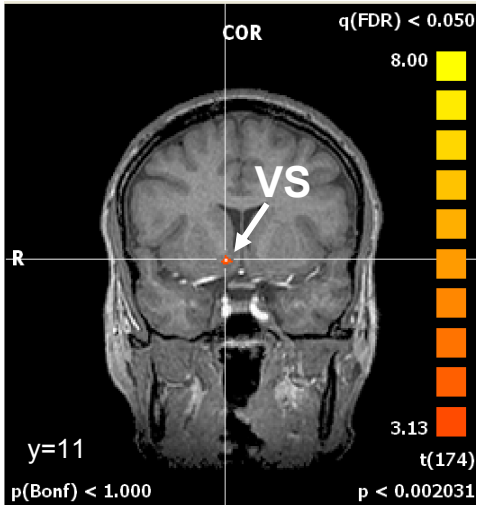


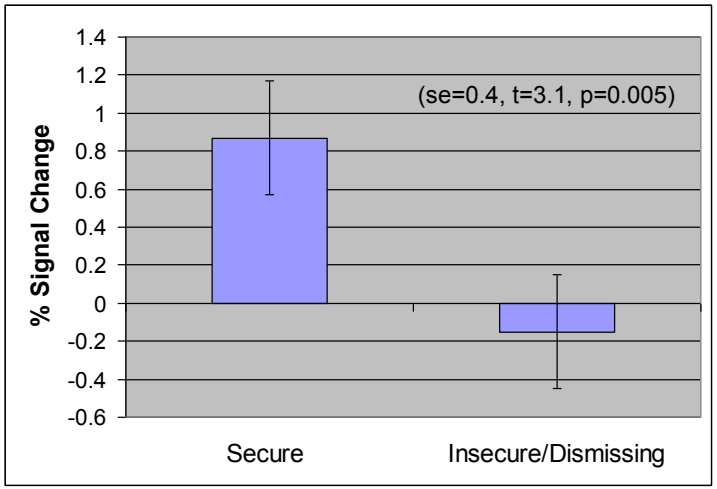
SECURE	INSECURE / DISMISSING
• Medial PFC • Orbitofrontal cortex • Ventral striatum	• Dorsolateral PFC
• Ventral striatum	• Dorsolateral PFC • Anterior insula

Own Sad Faces: Secure vs. Insecure Attachment

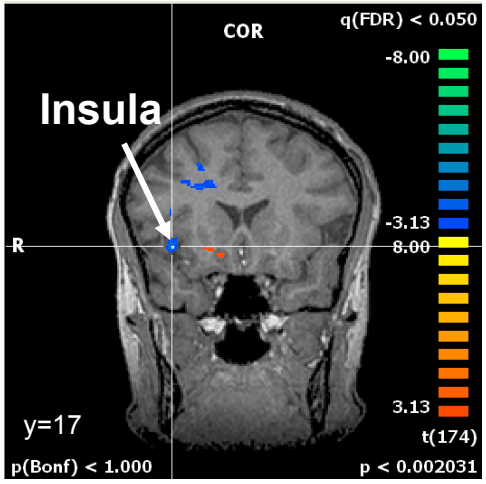
R Ventral Striatum

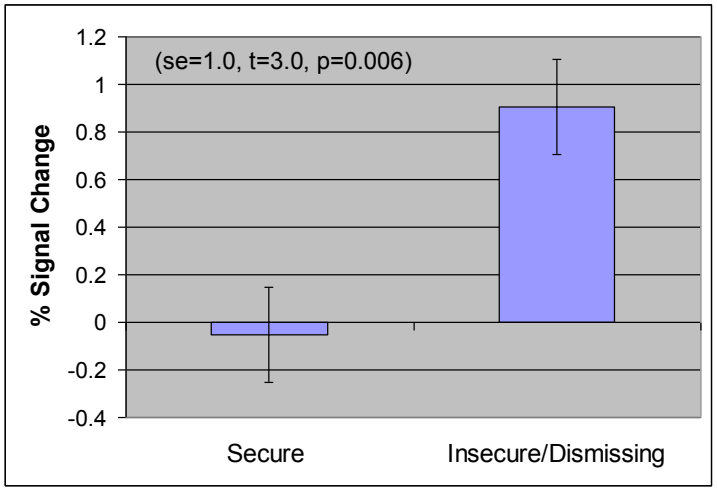




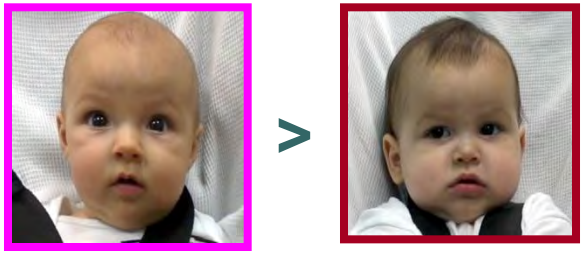


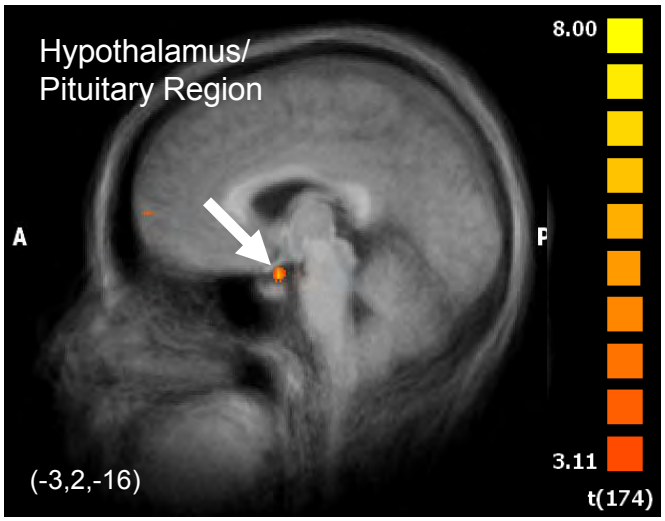
R Insula



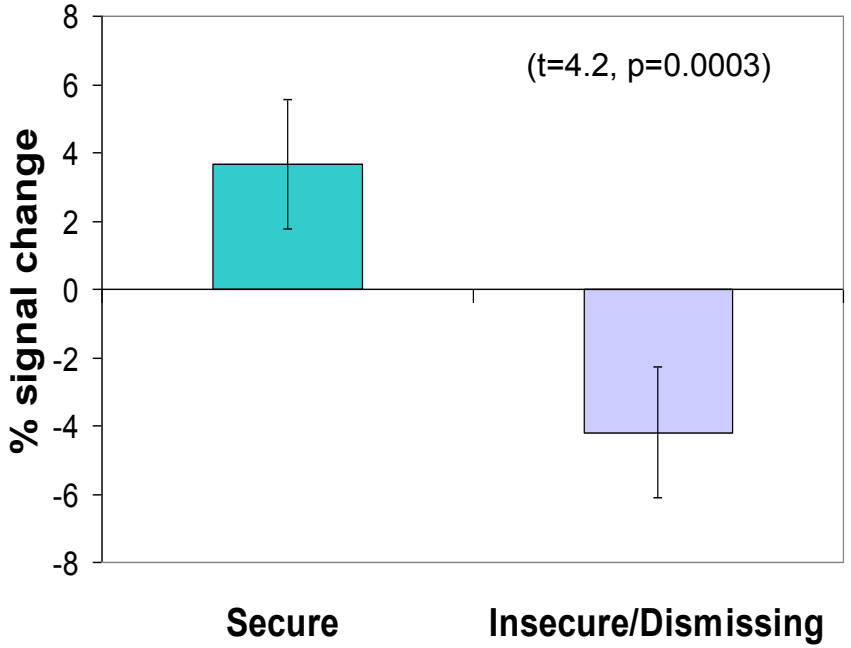


Own > Unknown Faces: Secure vs. Insecure Attachment

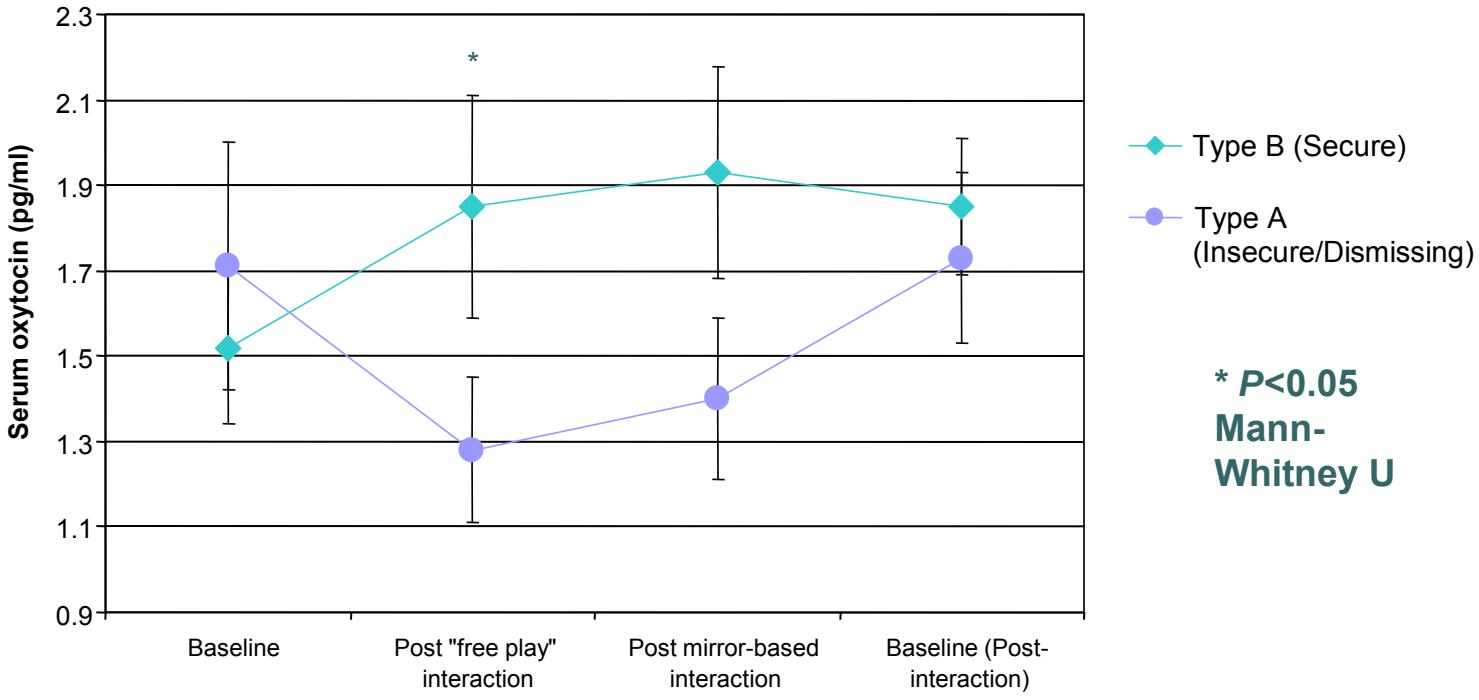




Hypothalamus/
Pituitary Region

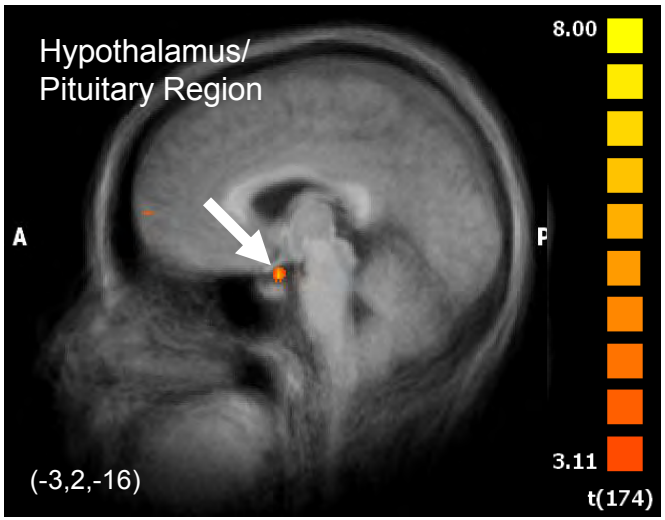


Change in peripheral OT with mother-infant interaction

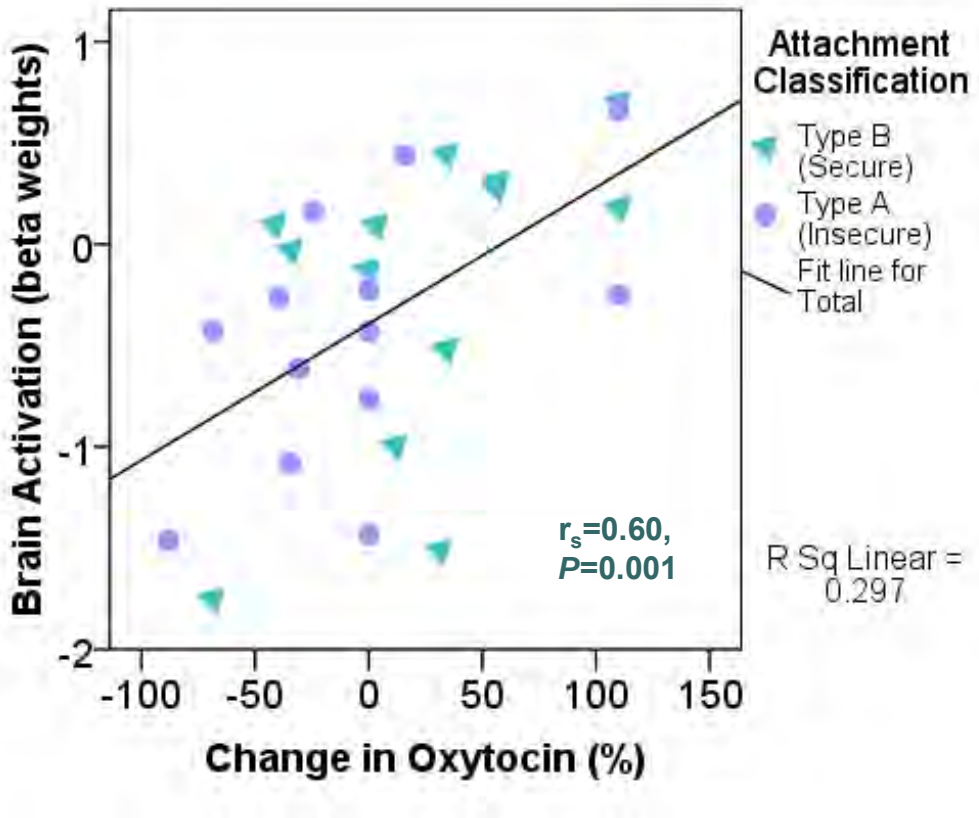


*** *P*<0.05 Mann-Whitney U**

Own > Unknown Faces: Oxytocin Response

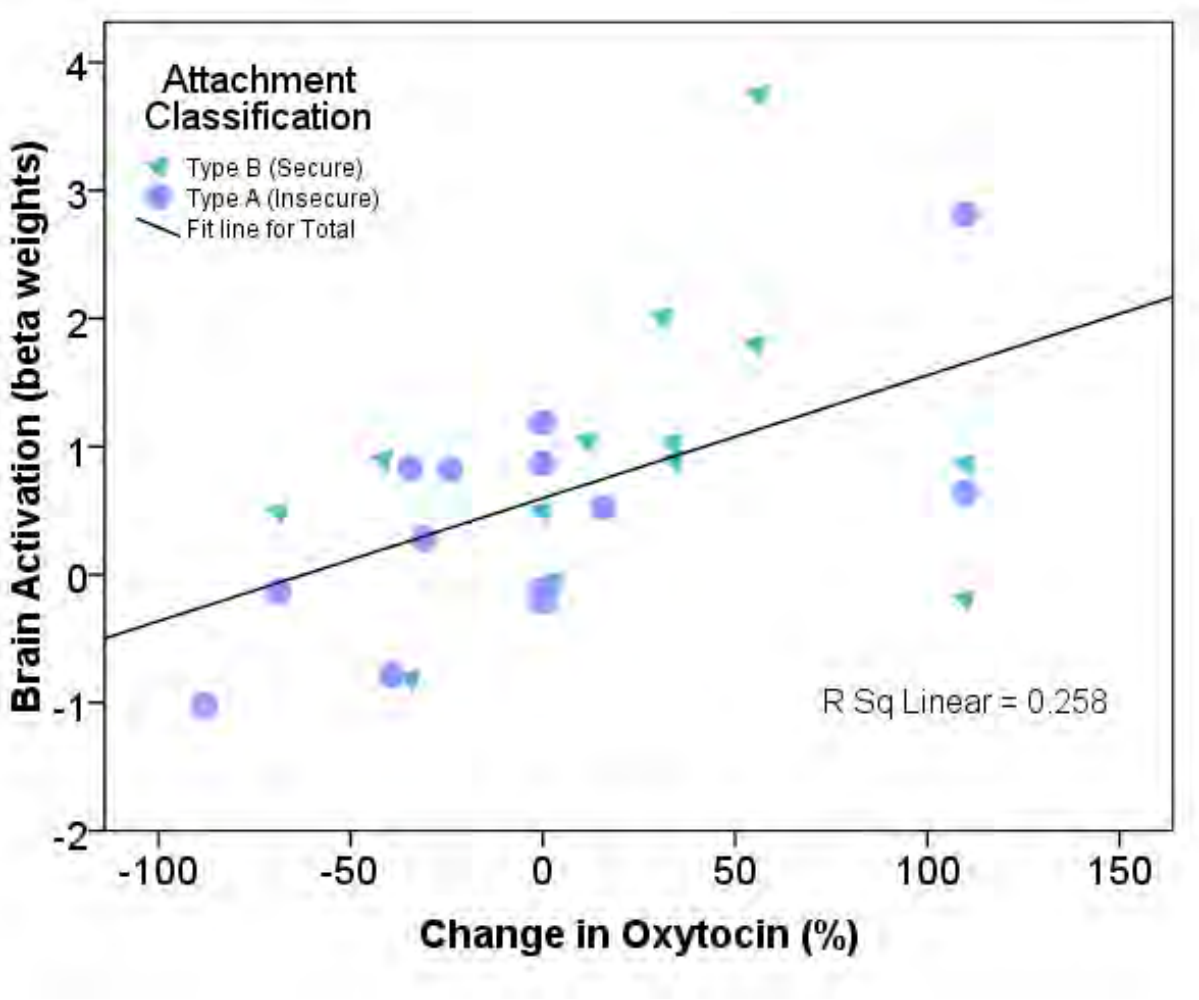


Hypothalamus/
Pituitary Region

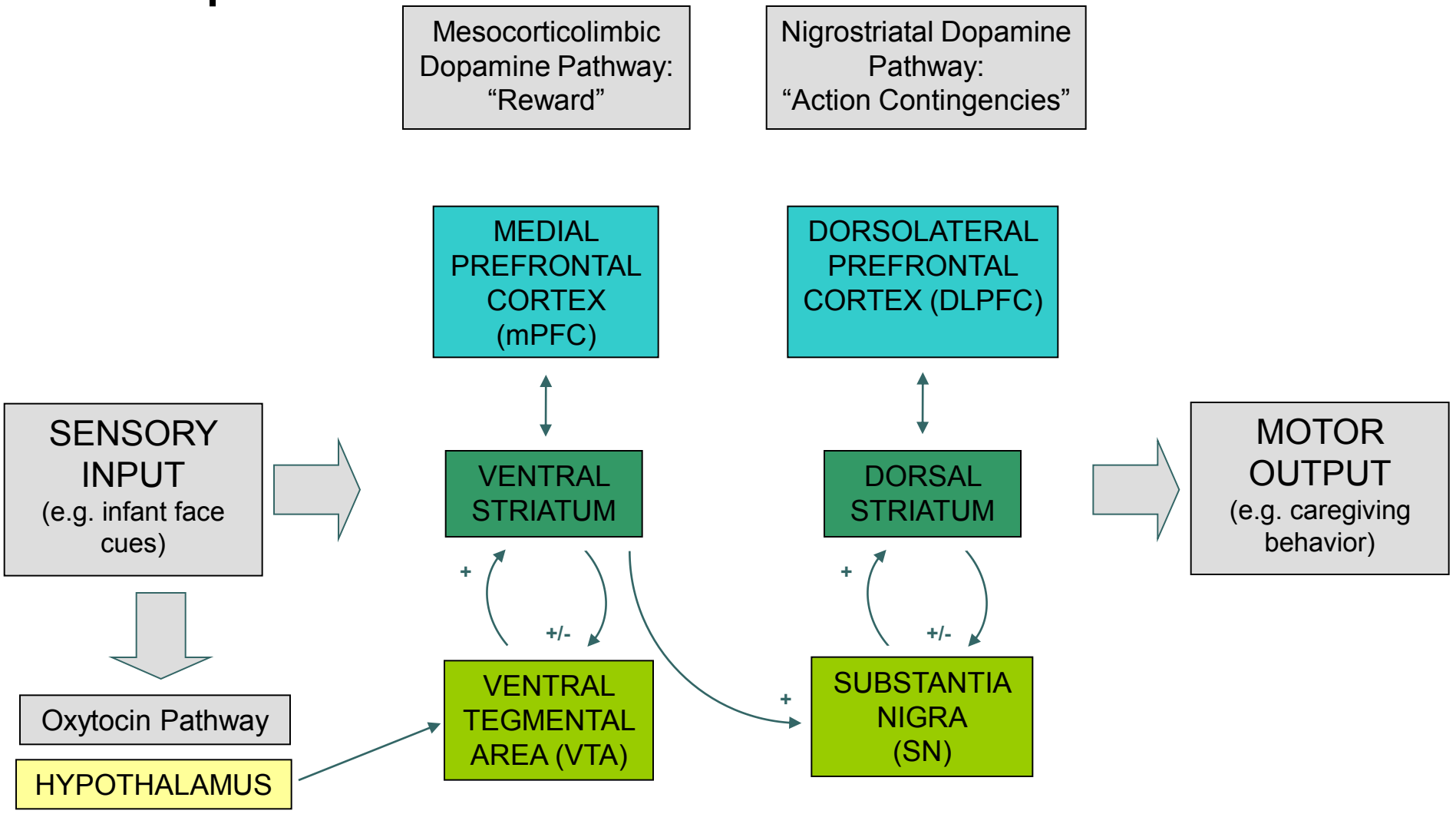


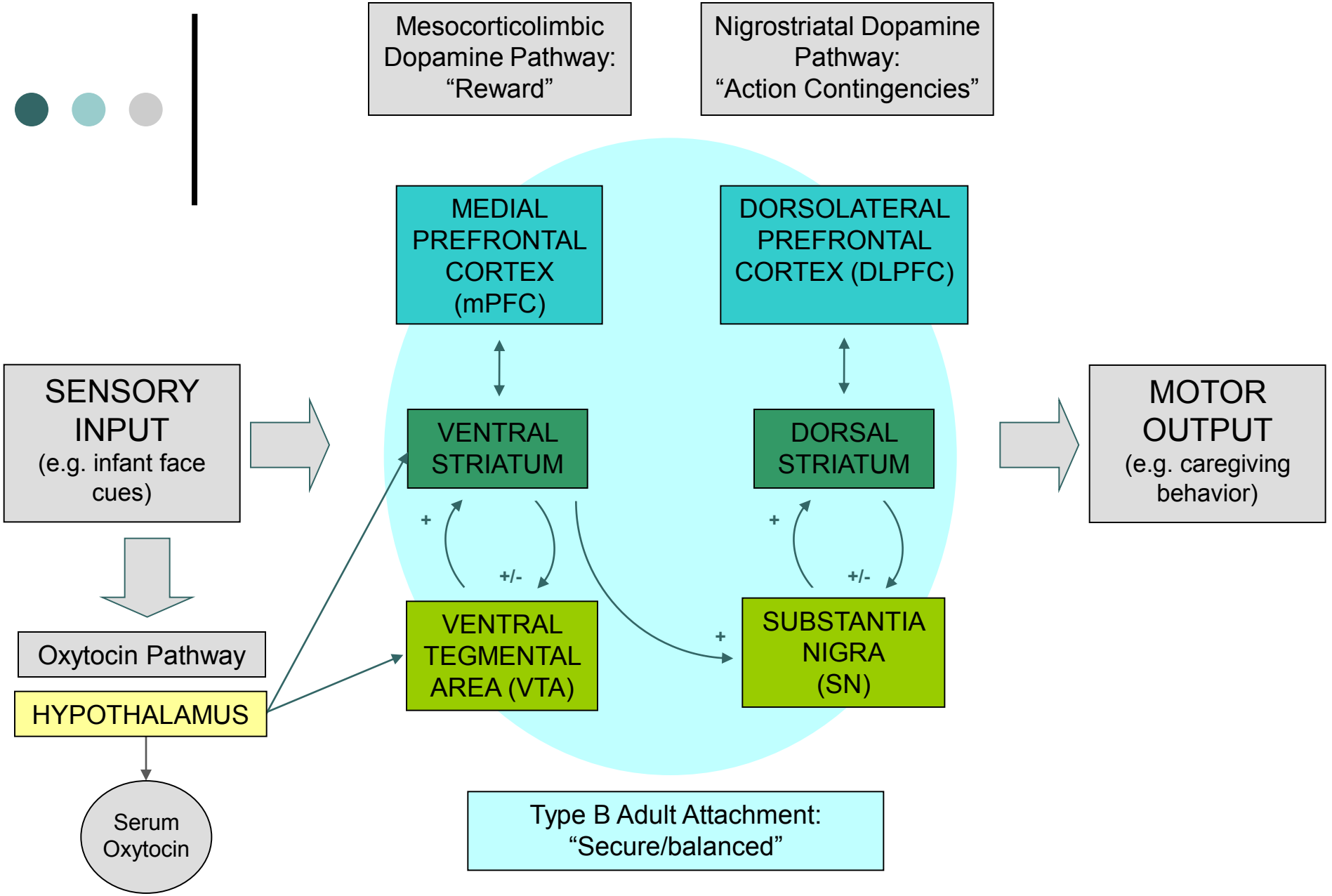
Oxytocin Response and Ventral Striatum Activation

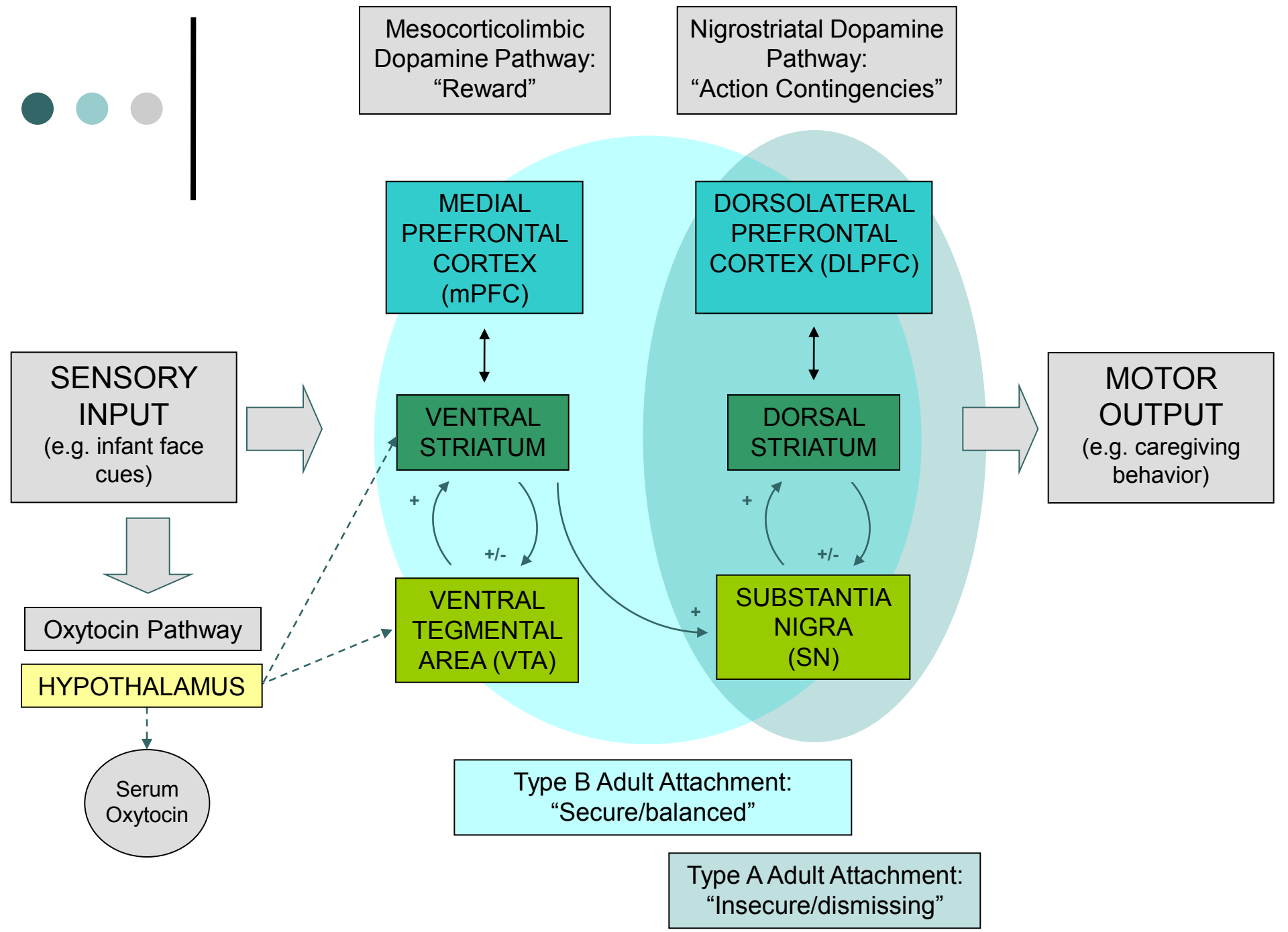
Ventral Striatum activation



Model: Maternal Brain Responses

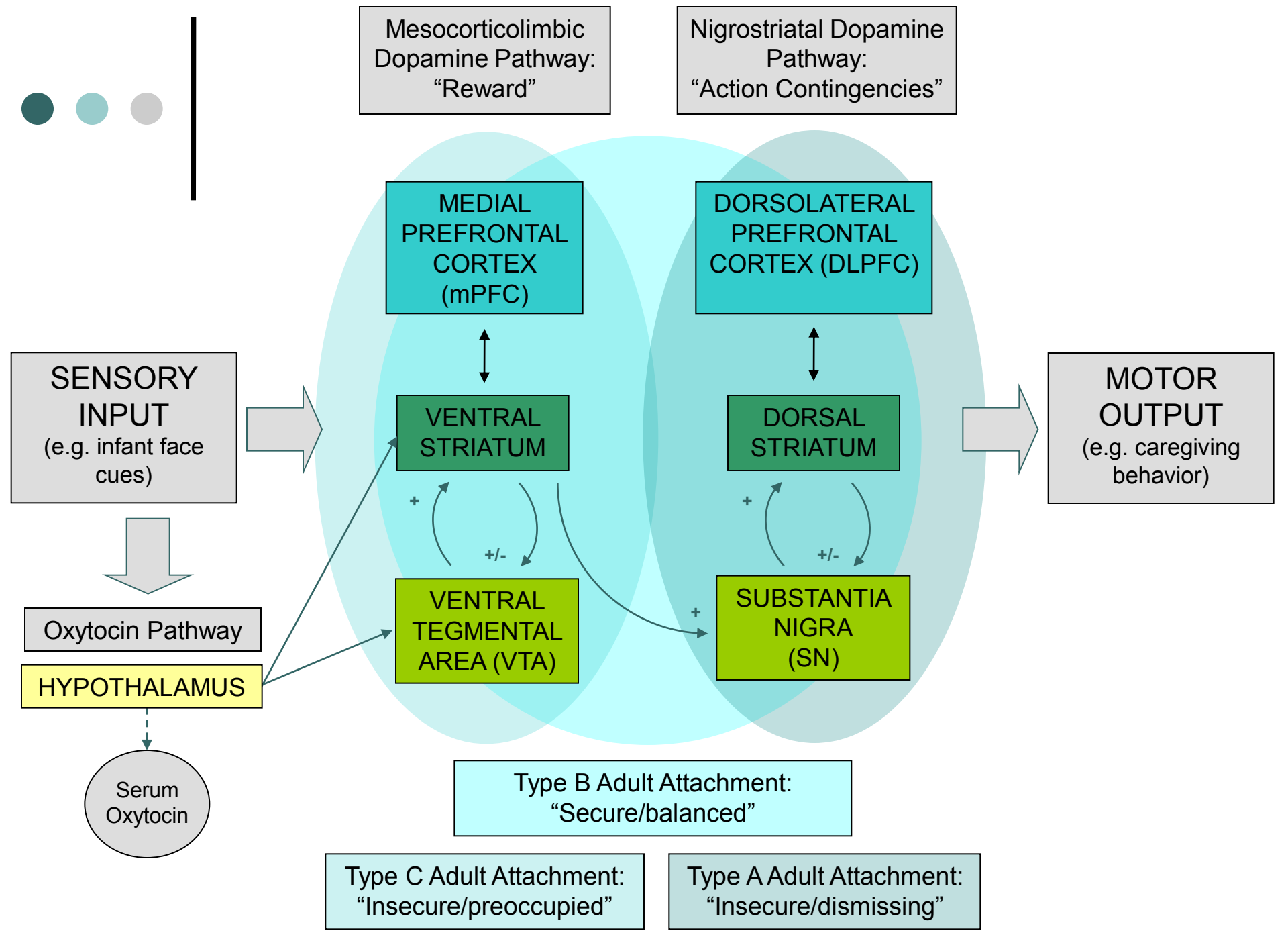



Mesocorticolimbic Dopamine Pathway: "Reward"
Nigrostriatal Dopamine Pathway: "Action Contingencies"
MEDIAL PREFRONTAL CORTEX (mPFC)
DORSOLATERAL PREFRONTAL CORTEX (DLPFC)
SENSORY INPUT (e.g. infant face cues)
VENTRAL STRIATUM
DORSAL STRIATUM
MOTOR OUTPUT (e.g. caregiving behavior)
+
+/-
+
+/-
Oxytocin Pathway
HYPOTHALAMUS
VENTRAL TEGMENTAL AREA (VTA)
+
SUBSTANTIA NIGRA (SN)
Serum Oxytocin
Type B Adult Attachment: "Secure/balanced"


Mesocorticolimbic Dopamine Pathway: "Reward"
Nigrostriatal Dopamine Pathway: "Action Contingencies"
MEDIAL PREFRONTAL CORTEX (mPFC)
DORSOLATERAL PREFRONTAL CORTEX (DLPFC)
SENSORY INPUT (e.g. infant face cues)
VENTRAL STRIATUM
DORSAL STRIATUM
MOTOR OUTPUT (e.g. caregiving behavior)
+
+/-
+
+/-
Oxytocin Pathway
HYPOTHALAMUS
VENTRAL TEGMENTAL AREA (VTA)
+
SUBSTANTIA NIGRA (SN)
Serum Oxytocin
Type B Adult Attachment: "Secure/balanced"
Type A Adult Attachment: "Insecure/dismissing"

Where to from here?

- Test hypothesis that "Insecure/Preoccupied" attachment is associated with reduced activation of nigrostriatal pathways


Mesocorticolimbic Dopamine Pathway: "Reward"
Nigrostriatal Dopamine Pathway: "Action Contingencies"
MEDIAL PREFRONTAL CORTEX (mPFC)
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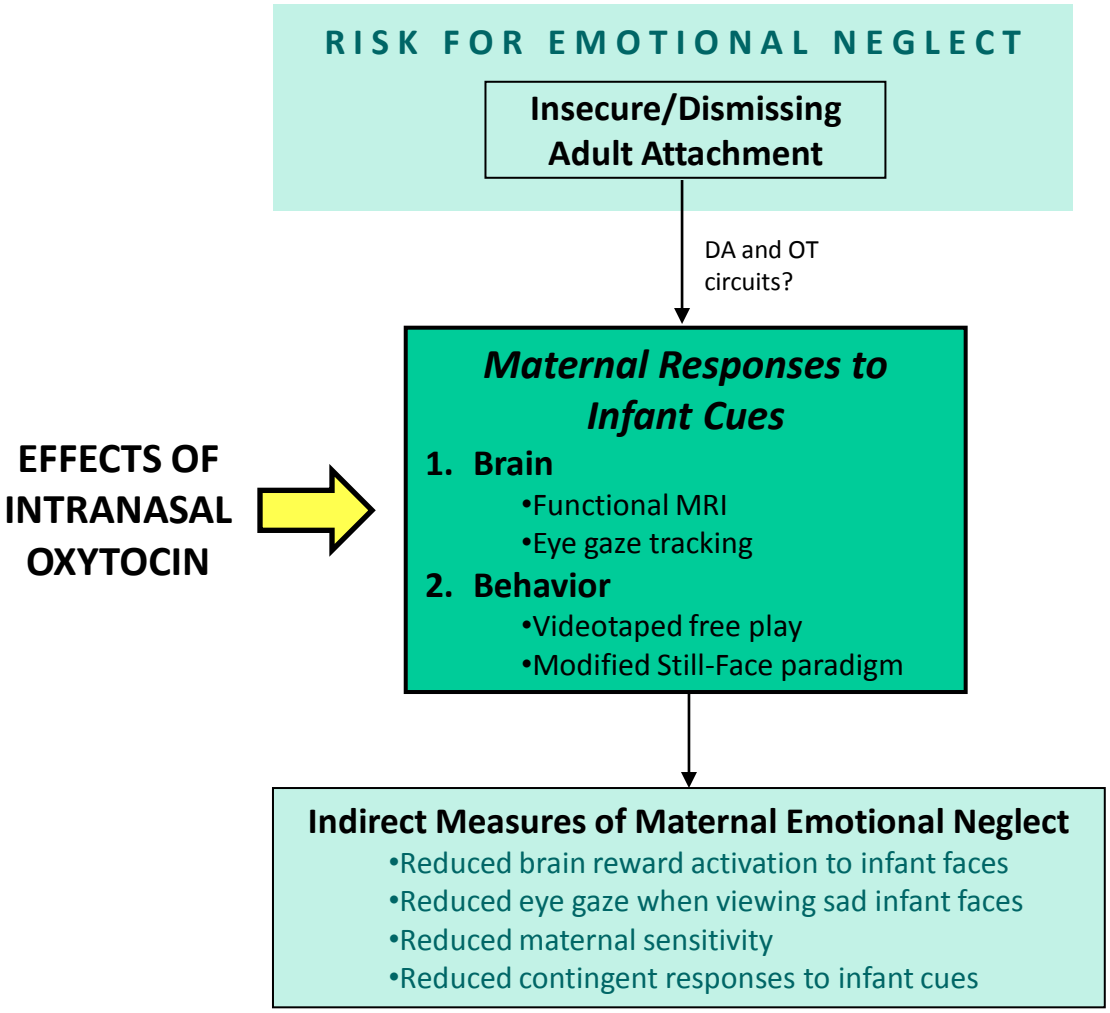
SENSORY INPUT (e.g. infant face cues)
VENTRAL STRIATUM
DORSAL STRIATUM
MOTOR OUTPUT (e.g. caregiving behavior)
+
+/-
+
+/-
Oxytocin Pathway
HYPOTHALAMUS
VENTRAL TEGMENTAL AREA (VTA)
+
SUBSTANTIA NIGRA (SN)
Serum Oxytocin
Type B Adult Attachment: "Secure/balanced"
Type C Adult Attachment: "Insecure/preoccupied"
Type A Adult Attachment: "Insecure/dismissing"

Where to from here?

- Test hypothesis that "Insecure/Preoccupied" attachment is associated with reduced activation of nigrostriatal pathways
- Use this paradigm to test whether maternal brain responses are altered by intranasal oxytocin

Future Directions

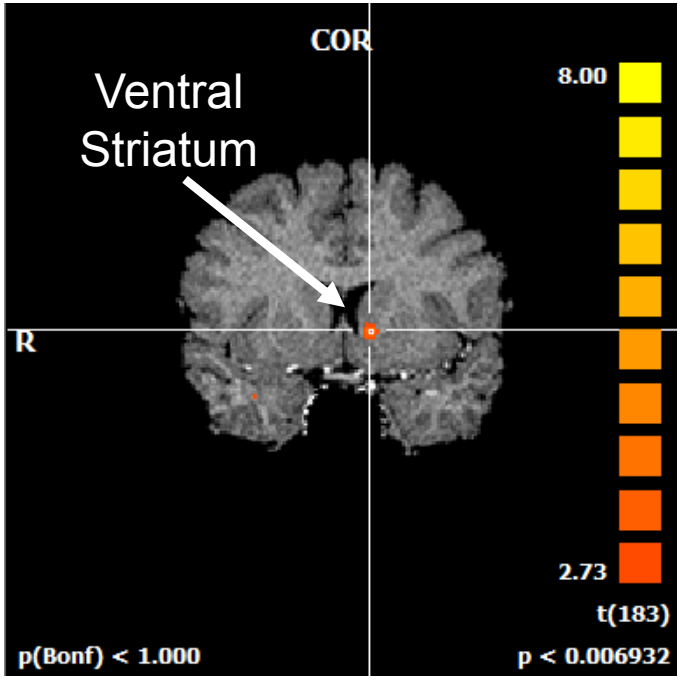


Own-
Happy Infant

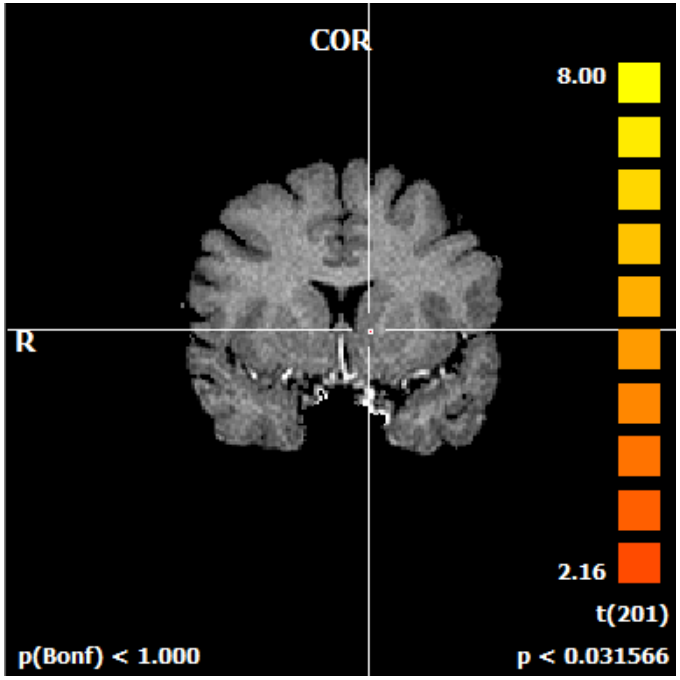
>

Unknown-
Happy Infant

Oxytocin

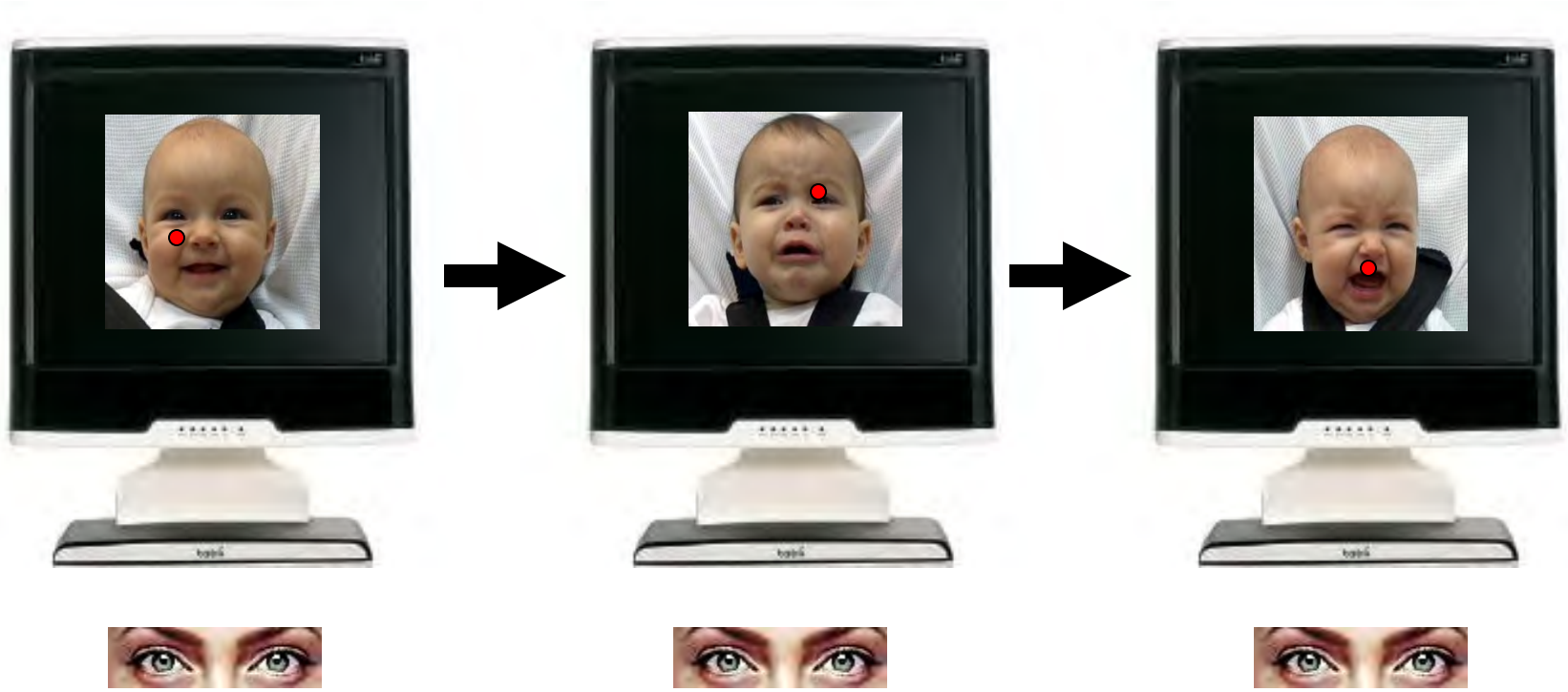


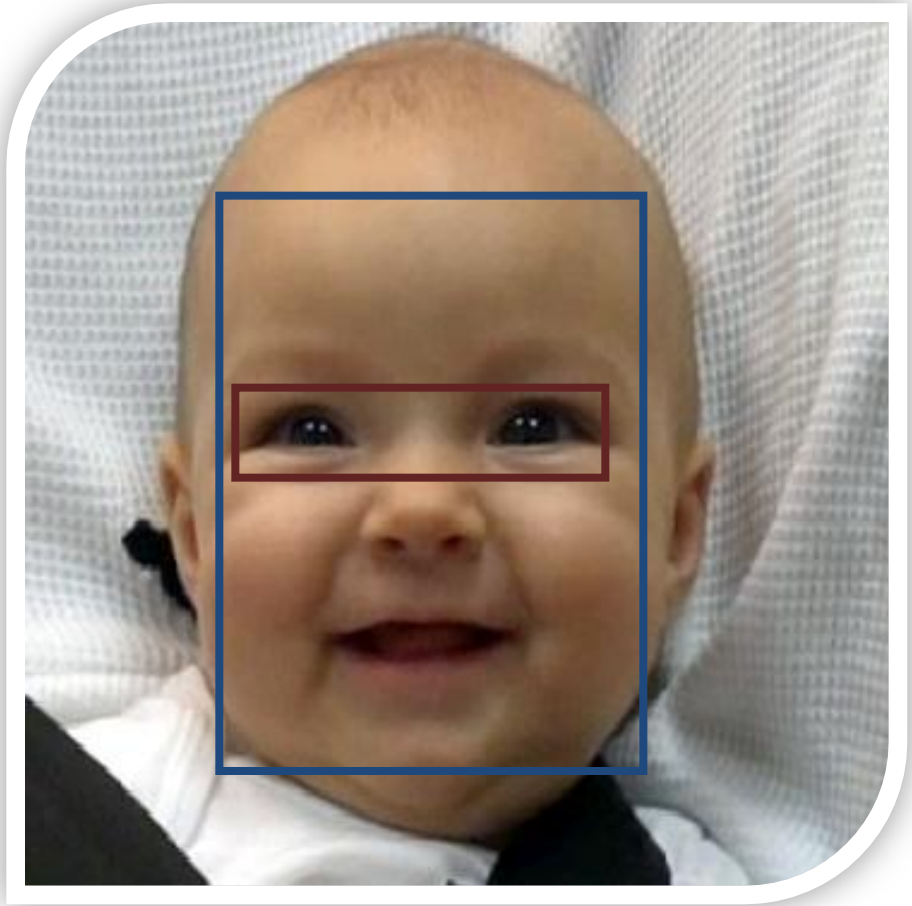
Placebo



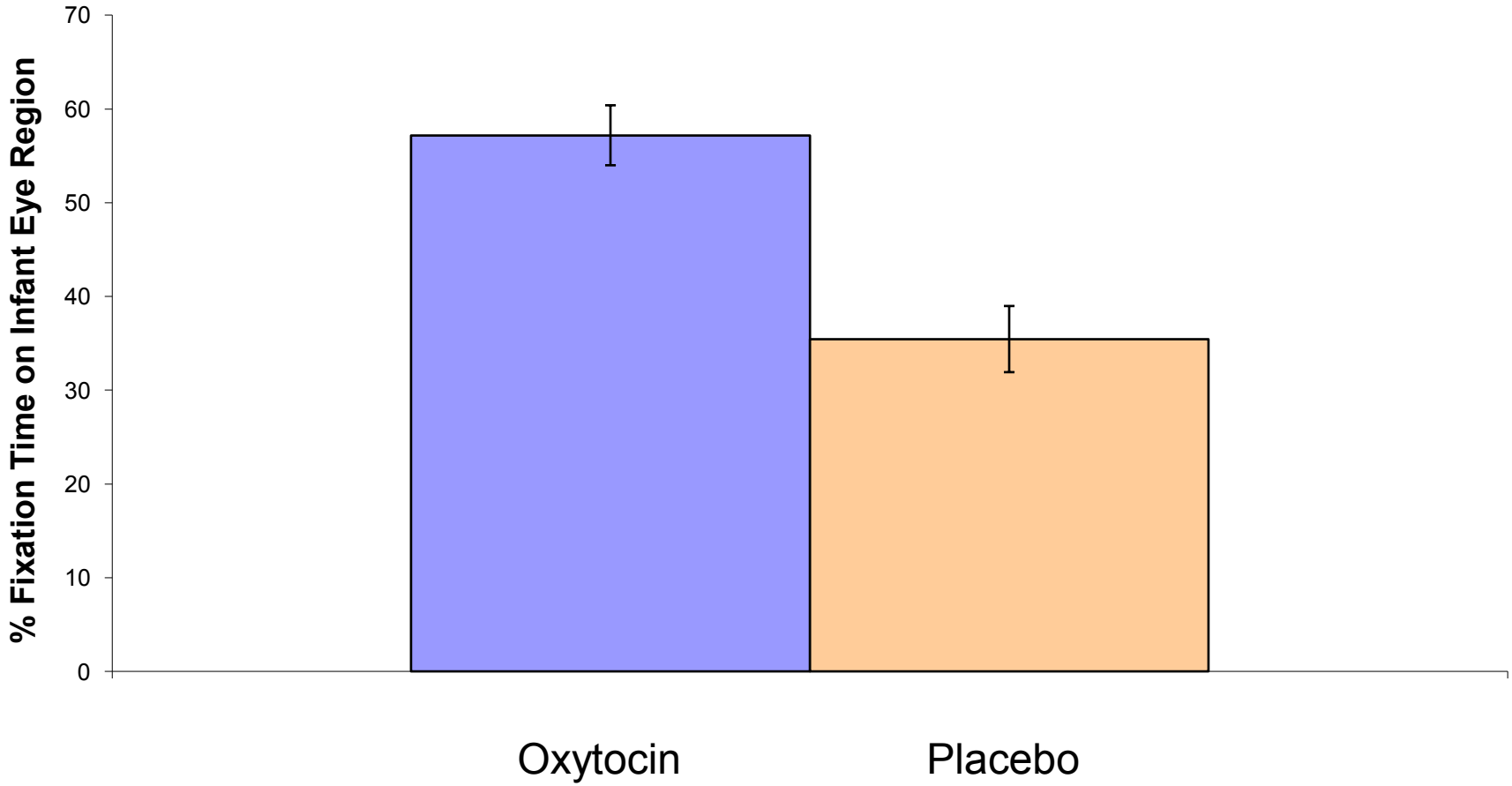
(x=-10, y=8, z=4)

Eye tracking and oxytocin





Intranasal oxytocin increases mother-infant eye gaze in Type A mother



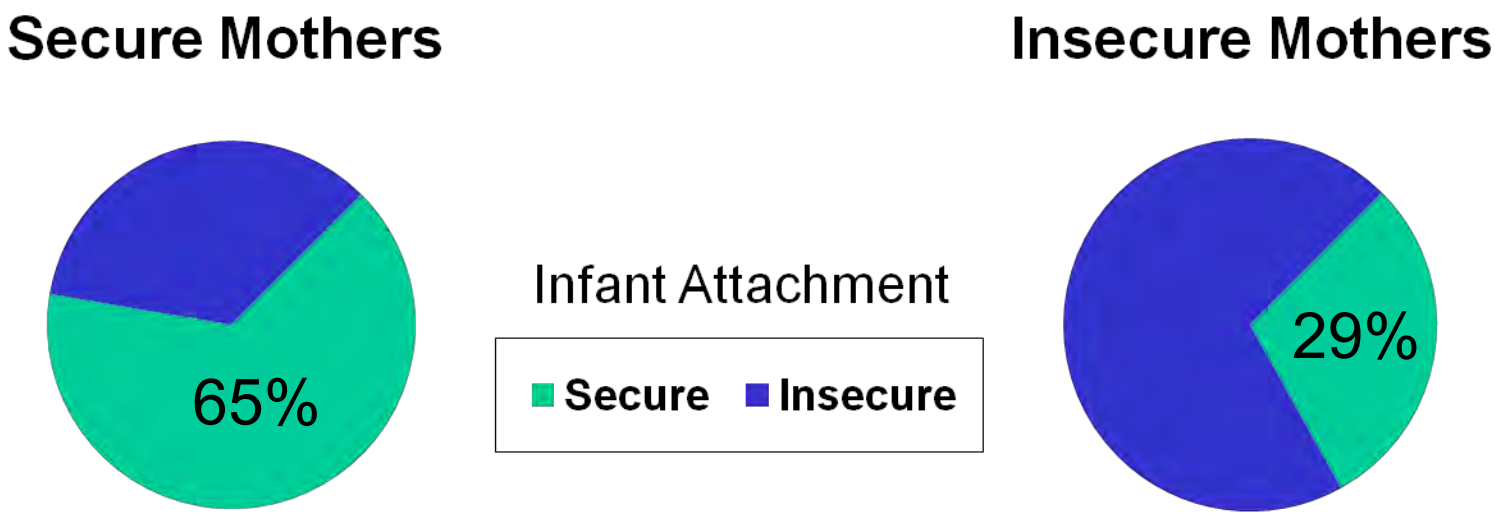
Where to from here?

- Test hypothesis that "Insecure/Preoccupied" attachment is associated with reduced activation of nigrostriatal pathways
- Use this paradigm to test maternal brain responses in drug addicted mothers
- Explore how maternal brain responses predict infant attachment outcomes, via Strange Situation Procedure

Intergenerational Transmission of Attachment

- Overall, there was a 73% match of secure/insecure attachment between mothers and infants (X^2 = 10.7, df = 1, κ = 0.46, p = 0.001)

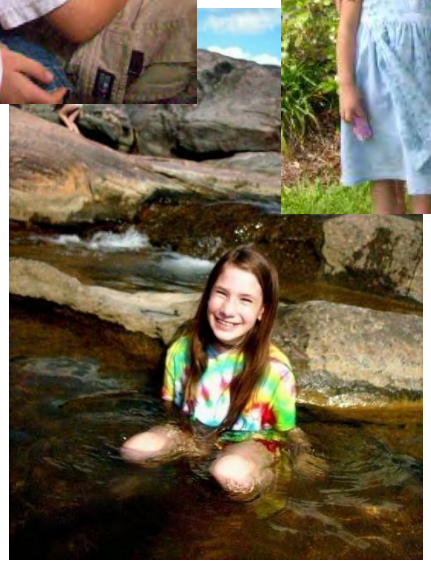
Intergenerational Transmission of Attachment

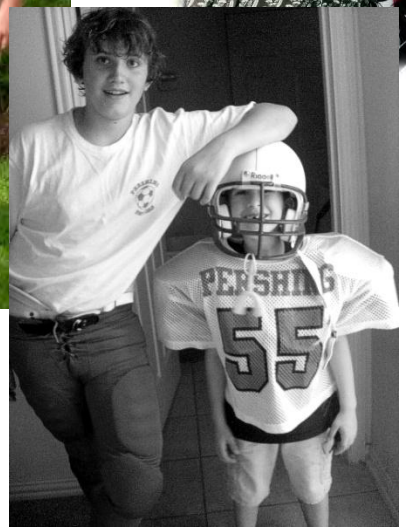


Acknowledgements

- Human Neuroimaging Lab
  - P Read Montague
  - Jian Li
  - Nathan Apple
  - Claudia Bracero, Krystle Bartley, Jonathan Wrathall
- Anna Freud Center, University College London
  - Peter Fonagy
- Funding Support
  - NICHD K23 HD043097
  - NIH K12 HD41648
  - GCRC at Baylor College of Medicine
- …and last but not least…

…my own model of maternal care





lanes@bcm.edu