The Parental Brain
Regulation of Mother and Father Behavior
that Influences Infant Development

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Introduction to the Brain Science of Parenting

Approaches: Human Brain Imaging and interview study design

Combining Brain Imaging with Interview & Video Parenting Assessments in Health, Postpartum Depression & Substance Abuse

Neurobiology of Parenting Interventions

The Environment of Poverty for Children and Parents

Significance and Future Directions
The Healthy Parental Brain – *In Action*
“I do not believe it is possible to understand the functioning of the mother at the very beginning of the infant’s life without seeing that she must be able to reach this state of heightened sensitivity … almost an illness… and recover from it.”

D. Winnicott
Special Nature of Postpartum:

- Parenting measurable as brain sensitivity to baby stimuli?
- Altered mental/emotional state
- Preoccupations, idealizations, compulsions, worries…like OCD
- Profound changes in salience evaluation and motivated behaviors
- Parents are transformed – brains are plastic – and therefore subject to gender, timing, experience, delivery, mood, anxiety, and SES
- Emotion Regulation, ToM, joy, reward and approach motivation
- Evolutionarily conserved…

Leckman, Feldman, Swain, et al., 2004; Swain et al., 2014
Biology of Parenting

- certain brain structures (MPOA, BNST, Amygdala, VTA) and certain hormones (oxytocin, estrogen, prolactin, oxytocin) and genes (prolactin and estrogen receptors, DA signaling) support parenting behaviors

Numan, 1994; Pederson et al., 1994; Sheehan et al., 2000; Leckman & Herman, 2000; Bridges, 2008

Transmission of Stress & Behavior to Infants

- variations in maternal care alter the expression of genes that regulate behavioral and endocrine responses to stress in offspring (partially independently of genetic endowment) as well as later maternal behavior of offspring (oxytocin dependent)

Meaney et al., 2001; Fleming et al., 2002; Kaffman et al., 2005
Neural Basis of Maternal Behavior: *Rodent Data ➔ Human Brain*

Swain et al., 2007; Swain, 2011; Swain et al., 2014
Talk Overview

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Birth Brain Structurals & Responses to Baby Stimuli

Experimental Design

Conception

Birth

Childhood

Interviews + MRI

2-4 Weeks Time 1

3-4 months Time 2

Mothers

Fathers

+ 1-8 years

…adulthood

Experimental Design

Brain Structurals & Responses to Baby Stimuli

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2-4 Weeks Time 1

3-4 months Time 2

Mothers

Fathers

+ 1-8 years

…adulthood
10-second rests between 30-second blocks
10 blocks per run (4 runs, each 6:40)
Blocks alternated over 4 runs, totaling 5 blocks for each condition (150s, 75 fMRI acquisitions)
Auditory Baby Stimuli Paradigm

- 10-second rest between 30-second blocks
- 10 blocks per run (2 runs, each 6:40)
- Blocks alternated over 2 runs, totaling 5 blocks for each condition (150s, 75 fMRI acquisitions)
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Baby Stimuli
Which Parent Brain Areas Respond to Own Baby Pictures at Time 1?

1st Mothers (n=19), own > other

- CINGULATE*
- MIDBRAIN*
- BASAL GANGLIA*
- THALAMUS
- AMYGDALA
- FACE AREAS
- HIPPOCAMPUS*
- VISUAL CORTEX

*CORRELATIONS WITH PARENTAL SENSITIVITY

Bartels & Zeki, 2004; Noriuchi et al., 2008; Strathearn et al., 2008/9; Barrett & Fleming 2011; Swain, Spicer, Feldman, et al., in prep
Parental Brain Response to Picture Own vs. Other **Summary**

- In mothers – 1\textsuperscript{st} time and veteran
  - Own picture > other picture: amygdala, insula, cingulate and superior temporal gyrus (STG)
  - Correlations with behavioral measures of parental sensitivity in ventral tegmentum, superior temporal gyrus
  - Sex, timing, experience differences, variations with mood and anxiety

Swain et al., 2007; Swain, 2011; Swain, Kim, et al., 2014

- In mothers, 3-6 months postpartum:
  - Pictures and videos: own > other video
  - Amygdala, striatum, correlations with OT/VP

Barrett & Fleming; Atzil, Feldman & colleagues, 2011/12; Swain Spicer, Feldman et al. in prep
Parental Brain Response to Cry
Low-Risk Summary - 1

- **Grouping All Parents: Similarities**
  - **Other cry > control sound**: insula, cingulate and superior temporal gyrus (STG) (**social emotion integration**), stable over 1st 4 months postpartum, greater in parents than non-parents
  - **Own cry > control sound**: same areas + frontal & limbic areas + correlations with PITA in insula/OFC (**worry**) at Time 1, **striatum** (**reward**) at Time 2
  - **Own vs. Other cry**: STG, insula, cingulate, ventral striatum & putamen
  - **Mothers and Fathers**...cry-response similarities in OFC and insula + correlations with caring thoughts and behaviors (maternal sensitivity)

Swain 2011; Swain, Kim and Ho, 2011; Swain et al., 2014 (in submission)
Parental Brain Response to Cry Low Risk **Summary - 2**

**Parental Groupings:** *Individual Differences*
- according to parental sex, experience & timing over first 4 months postpartum (Swain, 2011+ in press/prep)

- cesarean section < vaginal (Swain, et al., 2008)

- breastfeeding > formula feeding (Kim, et al, 2011)

- correlation with parental sensitivity objective measures with video (Kim et al, 2011; Swain, Sooriyakumaran, Feldman, et al., in prep)

- increased in ER regions with early-life perceived maternal care (inverted in HC) (Kim, et al., 2010)

- increased responses in premotor areas and relate to cultural similarity (Bornstein, et al., submitted, 2014)
Mothers in 11 cultures universally respond to their infants’ vocal distress by picking up and holding and by talking to their infant… NOT: displaying affection, distracting, or nurturing the infant.

Own Baby’s Cry > Control Sound

Bornstein, Putnick, Swain, et al, under review PNAS, 2014
Does Maternal Brain Structure Change Over Time?

First-time Mothers (n=19): Time 2 (2-4 weeks) > Time 1 (12-16 weeks)

- NO DECREASES

CORRELATIONS WITH POSITIVE PERCEPTIONS OF BABY

Kim, et al., 2010
How about Father Brain Structure Change Over Time?

Fathers (n=16): Time 2 > Time 1

Kim, Rigo, Mayes, Feldman, Leckman, Swain et al., 2014
OFC Change related to Paternal Intrusiveness

Fathers (n=16): Time 2 > Time 1

sgACC Change related to Paternal Mood

Kim, Rigo, Mayes, Feldman, Leckman, Swain et al., 2014
PD: assesses “self-oriented” feelings of personal anxiety and unease in response to others’ tense experiences.

EC: assesses feelings of compassion and concern for unfortunate others.

FS: assesses respondents’ tendencies to transport themselves imaginatively into the feelings and actions of fictional characters.

Mothers (n=14): child age 3.9
Parental Brain – Decision Making & Stress

Positive > Negative Feedback Inversely Related to Cortisol Reactivity

Septal-Hypothalamus Functional Coupling during Negative Feedback Inversely Related to Cortisol Reactivity

Ho, Konrath, Brown Swain, 2014
What about parental brain and risk for psychopathology?

- Opiate and other drug exposure
- High Parental Stress
- Adolescence
- Depression/Anxiety or Illness risk
- low SES/high stress
Opiate Exposed vs. Control
New Moms 2-4 weeks postpartum

(n=3 vs. n=3)

Ho, Swain, et al. 2013
Baby Cry is Stressful

Own Baby Cry > Control Sound inversely associated with CORT change

Own Baby Cry > Control Sound positively associated with CORT change
The *Depressed* Parental Brain
Depression: (Laurent & Ablow, 2012)

- Depressed vs. non-depressed mothers
- Own infant cry sound vs. control sound
- Depressed mothers showed less activation in:
  - Striatum (caudate, nucleus accumbens) and medial thalamic areas
  - Orbitofrontal, dorsal anterior cingulate, and medial superior frontal regions

Other work - Moses-Kolko, Hipwell, Wisner, Phillips
Parents with PTSD

- Using videos of parent-infant interactions
  - increased limbic responses, decreased cortical regulation (Schechter, Moser, et al., 2011; 2013)

- Using baby cry, picture and decision making tasks (Swain; Huth-Bocks, Ho et al., in preparation)
  - Well characterized sample - of low income mothers - facing multiple adversities including high rates of trauma exposure (both childhood maltreatment and adult intimate partner violence)
  - high insecurity, disorganized, frightening
  - ...

Listen to Cry as if Your Baby’s >
Listen to Control Sound

F-Test in Groups

F score

Healthy (n=23)
Remission (n=10)
Current (n=13)

Depression
Listen to Cry as if Your Baby’s >
Listen to Baby-Cry Passively

Low (n=23) < Medium (n=10) < High Risk (n = 13)

Depression
Listen to Cry as if Your Baby’s >
Listen to Baby-Cry Passively

Low (n=23) < Medium (n=10) < High Risk (n = 13)
Listen to Baby-Cry as if Yourself >
Listen to Baby-Cry Passively

F-Test in Groups

STRESS-RESPONSE

Hypothalamus

Healthy (n=23)
Remission (n=10)
Current (n=13)
Listen to Baby-Cry as if Yourself >
Listen to Baby-Cry Passively

F-test in Groups

Habenula

Learned Helplessness

Healthy (n=23)
Remission (n=10)
Current (n=13)
High-Risk - Take Homes:

- **Who’s Crying Task**
  - Anxious Mothers over-engage the amygdala...depressed mothers under-engage the amygdala (salience empathy) in the “your baby care” condition
  - Depressed mothers over-react in the habenula (related to errors and helplessness) in the self-care-oriented condition

- **WMCI Task**
  - Parenting function is inversely related to reflection-related amygdala responses and connectivity
  - Failure to regulate anxiety/fear circuits in reflective functioning

? Do Interventions Change the Brain ?
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Attachment Theory

Trauma-informed Care Theory

Relationship-Focused (Infant Mental Health)

Evidence-Based CBT, DBT, IPT, MI
Making Complex models accessible: Attachment Based Parenting
Parenting Training

Self-Care Skills Training

Practice Parent-Child Interaction

Connect to Services

Enhance Social & Peer Supports

Sustain

Reflect

Mom Power

Core Components

Connect
Baby Cry Task and Pre/Post Parenting Intervention = Mom Power

n=14 Mom Power, 15 wait list **
-high risk moms due to trauma exposure or mental illness

Own vs. Other Baby Cry
POST > PRE-MP

Own vs. other Baby Cry Response

Own vs. Other Baby-Cry
Inversely Related to PSI at T2 (After MP Intervention)

(a) l. Amygdala
(b) Precuneus
(c) aMCC
(d) dIPFC
Listen to Cry as Your Baby’s >
Listen to Baby-Cry Passively

Treatment-induced Change in Hypothalamus

High Risk with Treatment (n = 14) <
High Risk without Treatment(n = 15)

STRESS-RESPONSE
Face Mirror Task and Pre/Post Parenting Intervention = Mom Power

Join vs. Observe, POST > PRE-MP

dIPFC  b. Insula

Join vs. Observe Inversely Related to Parental Stress Index at T2

n=14 Mom Power, 15 wait list – age ~21; children aged 2-7
-high risk moms due to trauma exposure or mental illness
Conceptual Framework - Parental Brain - Intervention

OUTCOMES

- Parental Stress (PSI, cortisol)
- Parental Function (sensitivity)

MATERNAL CARE

Emotion Regulation
- Guided parent-child interactions
- Mental Health and self care

NEURAL NETWORKS
- Amygdala, aMCC
dlPFC, Precuneus
- dlPFC, Insula

Empathic Functioning
- Attachment based parenting education

Past or Present Psychopathology
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Low Socioeconomic Status

- 1/5 of American children grow-up in poverty
- Federal Poverty Level ~$15K for 2 people
Low Socioeconomic Status

- Poverty is harmful to:
  - Development
  - Health
  - Achievement
  - Socio-emotional adjustment – anxiety, depression, attentional, hyperactive & conduct problems
Low Socioeconomic Status

**Figure 1**
Mortality Rate by Socioeconomic Status Level

Note. (a) Standardized mortality ratio, observed to expected deaths (SMR) male (Kitagawa & Hauser, 1973). (b) SMR female (Kitagawa & Hauser, 1973). (c) SMR male (Adelstein, 1980). (d) SMR female (Adelstein, 1980). (e) Annual death rate per 1,000 (ADR) male (Feldman, Makuc, Kleinman, & Cornoni-Huntley, 1989). (f) ADR female (Feldman et al., 1989). (g) Infant mortality per 1,000 live births (IM) male (Susser, Watson, & Hopper, 1985). (h) IM female (Susser et al., 1985).

**Figure 2**
Morbidity Rate by Socioeconomic Status Level

Note. (a) Percent diagnosed osteoarthritis (Cunningham & Kelsey, 1984). (b) Relative prevalence of chronic disease (Townsend, 1974). (c) Prevalence of hypertension (Kraus, Borhani, & Franti, 1980). (d) Rate of cervical cancer per 100,000 (Devesa & Diamond, 1983).
Prevalence of Health Problems in Children

- Any limiting chronic condition
- Asthma prevalence
- Ear disease
- Injury
- Physical inactivity

SES (lowest to highest)
Cognitive Functioning in 12-year old Children

Language | LTM | WM | Executive Control
--- | --- | --- | ---
4.0 | 3.7 | 3.7 | 3.5

SD Separation Low vs. Middle SES
Low Socioeconomic Status & Brain

- PRIMARY AIM:
  - Determine how childhood poverty influences adult brain cortical morphology
  - Longitudinal – Evans cohort
    - I. Parenting
    - II. Allostatic load

- N=54 (26 low SES)
Among low-SES subjects:
What are basic brain circuit responses to *baby cry*?

Listen to Baby-Cry vs. Noise (n=26)

Your Baby vs. Noise (11 Parents > 15 Non-parents)

Swain et al., in prep, 2013
Own vs. Other Baby’s Cry

- In Low SES parents (n=11)

Left Insula Response to Own vs. Other Baby Cry

Habenula in Own vs. Other Baby Cry

Swain et al., 2013, in prep
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A. INFANT “INPUT” STIMULI:
Cry, Visuals, Touch, Smell

B. CORTICO-LIMBIC MODULES

(i) Sensory - Salience Detection – Motivation
- sensory cortex activity leading to activation of limbic areas for salience, motivation and reward
  (sensory cortex, amygdala, VS, hippocampus)

(ii) Reflexive Caring
- sensitive touch, vocalizations, feeding
  (hypothalamus, medial preoptic area, lateral septum, extended amygdala, thalamus)

(iii) Emotion Regulation
- top-down regulation of intense emotion
  (mPFC, ACC, OFC, insula)

(iv) Cognitions
- empathy, mentalization, TOM, complex planning
  (mirror neuron systems: frontal, insular & superior-temporo-parietal cortex, cingulate)

C. PARENTAL SENSITIVITY “OUTPUT” BEHAVIORS
- cortico-limbic modules interact and may be active simultaneously
- flexible cortical regions such as prefrontal and sensorimotor cortices – likely more important in humans than non-humans – orient, regulate affect and generate parent-infant interpersonal synchrony and sensitive parenting thoughts and behaviors
Thank You!

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