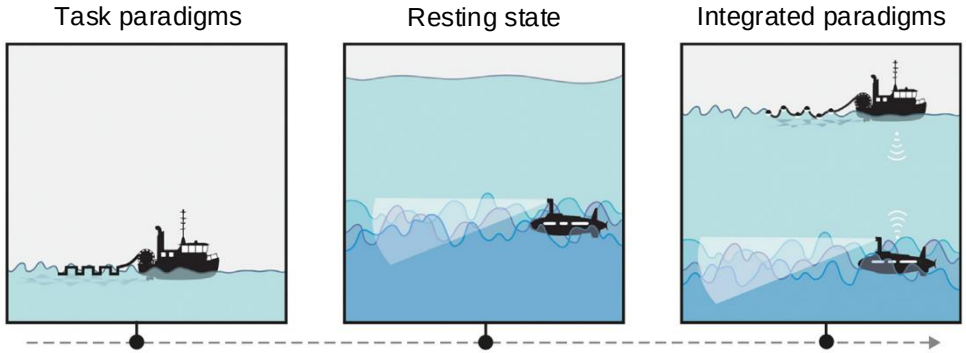
fMRI experiments

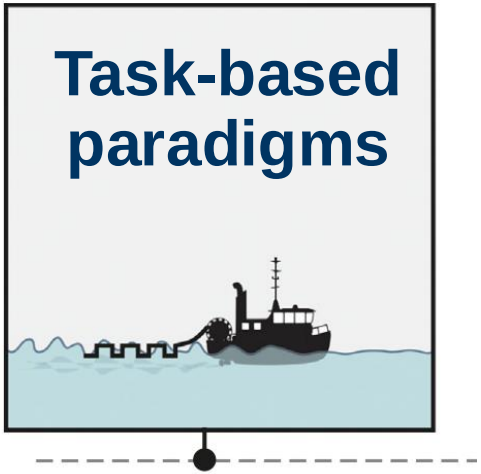
Discussion: Why do we have a brain?

Task-based vs. Task-free approaches in Cognitive Neuroscience



Finn, TICS, 2021

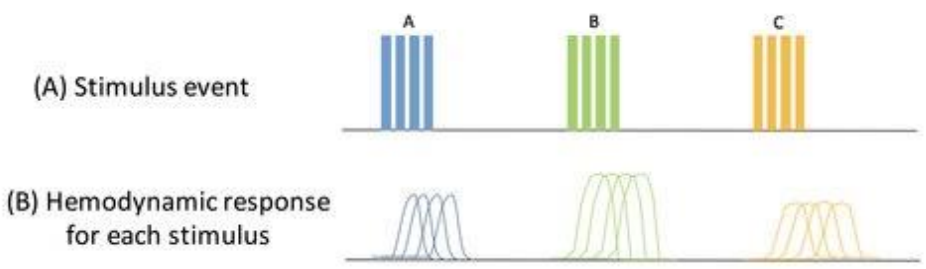
Task-based paradigms



What are task-based paradigms?

- Participants perform **tasks** or are exposed to controlled **stimuli.**
- Used to **investigate brain activity** associated with assumed **cognitive processes** (e.g., attention).

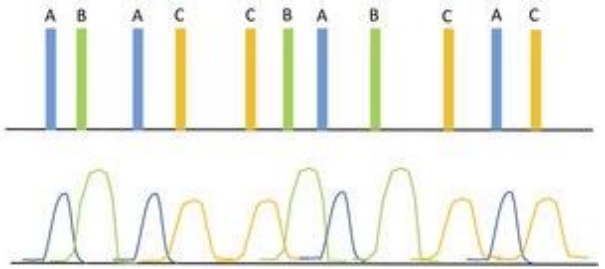
Block design



Strong BOLD response and thus high statistical power, simple to analyze.

Limited range of questions, unrealistic, susceptible to habituation effects.

Event-related design



Arco et al. 2018

Broad range of questions, self-paced tasks, trial-by-trial variability, less habituation.

Lower statistical power, requires more sophisticated timing and analysis.

- Tasks are performed through behavior → **Behavior needs to be measured!**

Ways to measure behavior & physiological signals in fMRI

Button boxes & joysticks

Basic behavioral responses

Eye tracking

Gaze behavior & pupil size

Microphones

Speech

Pneumagraphic belts

Breathing

Pulse oximeter

Blood oxygenation,
Heart rate

Experimental considerations

e.g., Video games

And more…

Ways to present stimuli

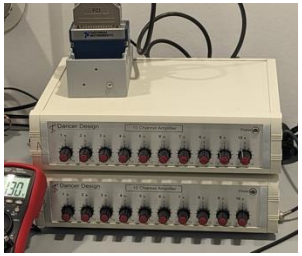
Screen + Mirror

Standard setup
for visual stimuli

Goggles & Headphones

3D stimuli, virtual reality,
sounds, narratives, music…

Vibration devices



Tactile stimuli, touch

Galvanic stimulator

Vestibular stimuli,
perceived movement

**Gustometers &
odor stimulators**

Taste, smells, flavors

Brain stimulation

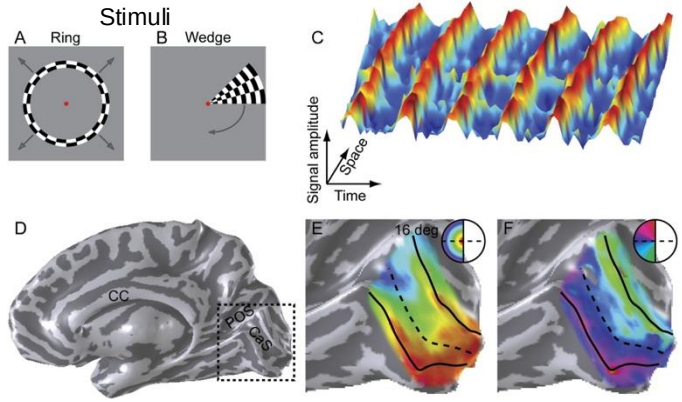
Magnetic or electrical
stimulation

And more…

Task-based paradigms: Different experimental philosophies

Experimental control ⟷ ‚Naturalistic' conditions

Example: Mapping visual receptive fields



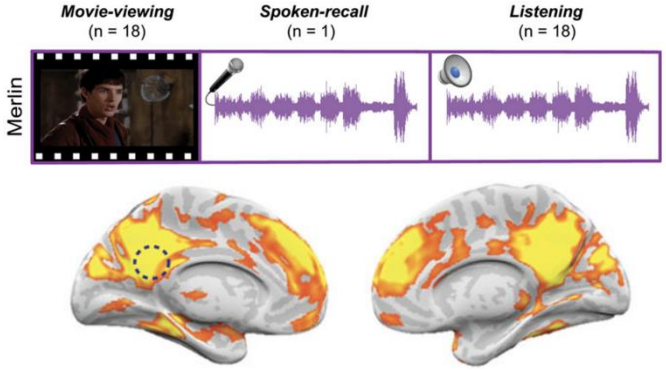
Dumoulin et al. 2008

Example question: How does the brain map space?

Stimulus: Tightly controlled content, timing, location

Instruction: Don't move, look at the red dot

Example: Similar brain activity between movie viewing, narratives, and spoken recall



Zadbood et al. 2017

Example question: What and how to we remember?

Stimulus: Visually rich, dynamic movie with narrative

Instruction: Watch the movie, tell us about it later

Task-based paradigms: Different experimental philosophies

Experimental control ⟷ ‚Naturalistic' conditions

- Clearer result interpretation
  (e.g., Factor A explains results, not Factor B)
- Many simple, feasible experiments & analyses
- Easier to standardize & replicate
- Analysis assumptions met through task design
  (e.g., covariance of predictors)

- Constrained & artificial conditions
- Results might not generalize to real world
- Solid interpretations require many controls
- Full control of behavior neither feasible,
  nor desirable for understanding the brain

- Closer to real life (Ecological validity),
  with better generalizability of results
- Interactions between factors can be studied
- Discovery of unexpected phenomena more likely
- Many engaging experiments (e.g., Games)
- Measuring rather than controlling behavior

- Result interpretation more difficult
- Invites unconstrained data exploration
- Analytical challenges (e.g., colinearity,
  missing data…)
- MRI experiments limited in terms of "naturalism"

Task-based paradigms: Different experimental philosophies

Experimental control ⟷ **‚Naturalistic' conditions**

Most studies are not one or the other!

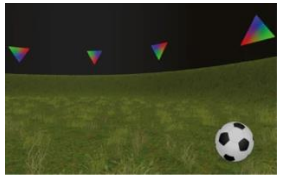
Example 1: Rendered stimuli

Schmid et al. 2023

Example 2: (Designed) Narratives & movies

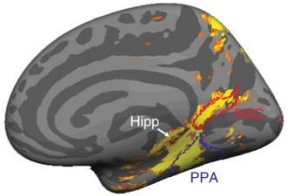
Willems et al. 2020

Example 3: Virtual reality



First-person view

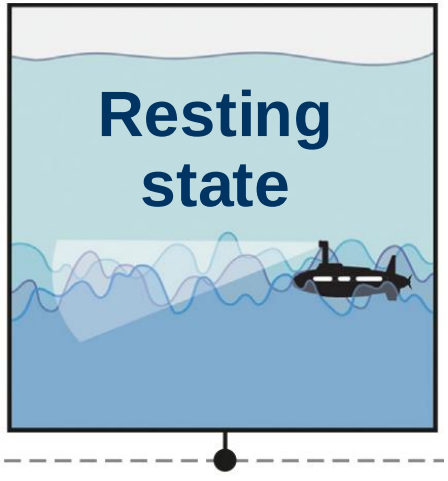
Nau et al. 2020



Brain regions involved in spatial navigation

Eppstein et al. 2017

Your research question determines how much experimental control is optimal!

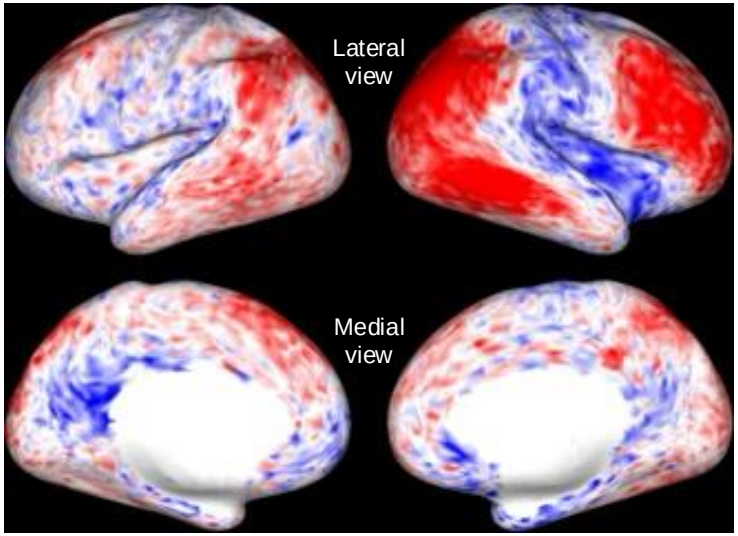

Resting
state

Resting state (rs-fMRI)

Typical experiment (>500 papers/year!): „Lie in the scanner and fixate at a dot (or close your eyes)”

Brain activity

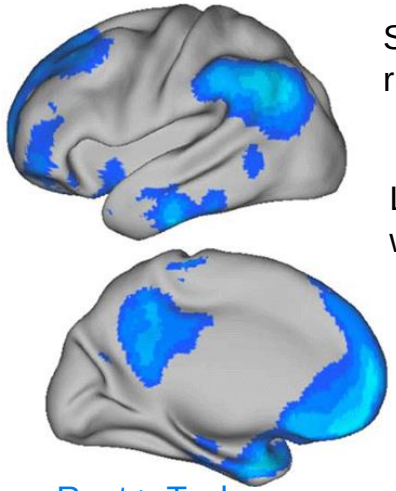
Bhushan et al. 2016



MRI signal while participants rest in the scanner:
Signal above average | below average

Default mode network (DMN)

Buckner et al. 2008



Rest > Task

Stronger signal during rest than during tasks

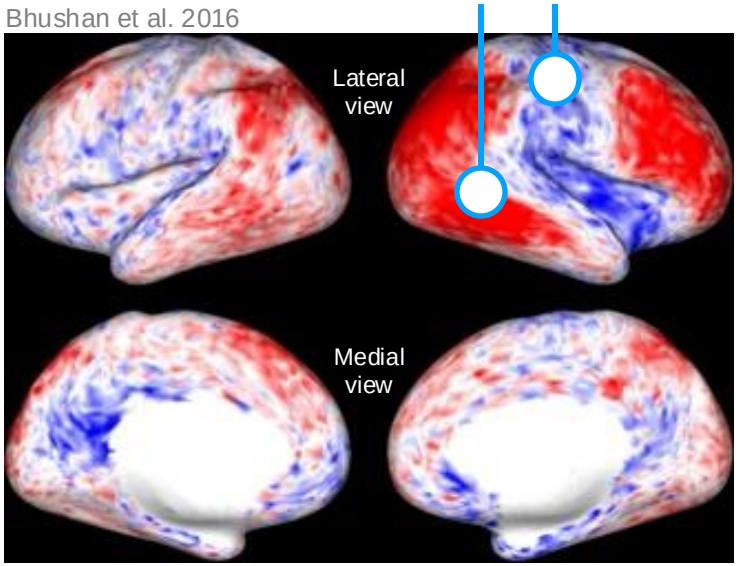
Large literature on mind wandering, memory etc.

Resting state (rs-fMRI)

Typical experiment (>500 papers/year!): „Lie in the scanner and fixate at a dot (or close your eyes)"

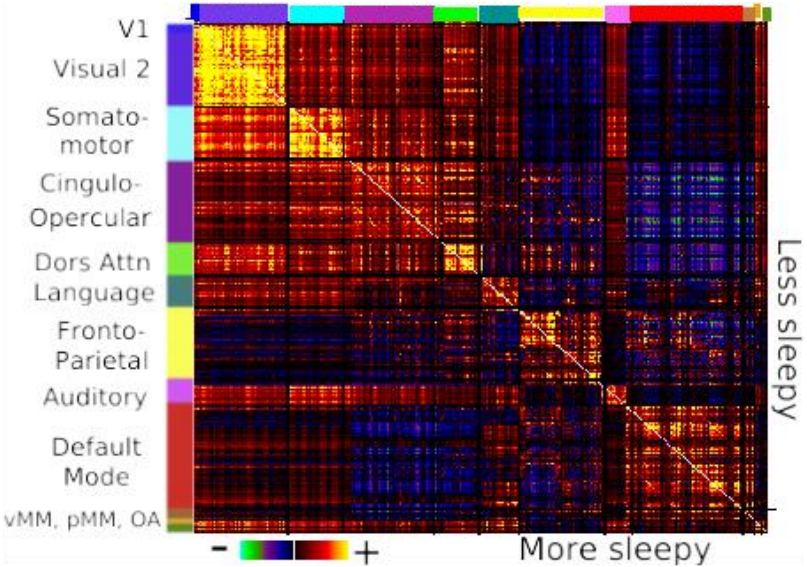
Brain activity **Covariation?** → **Functional connectivity**

Bhushan et al. 2016



MRI signal while participants rest in the scanner:
Signal above average | below average

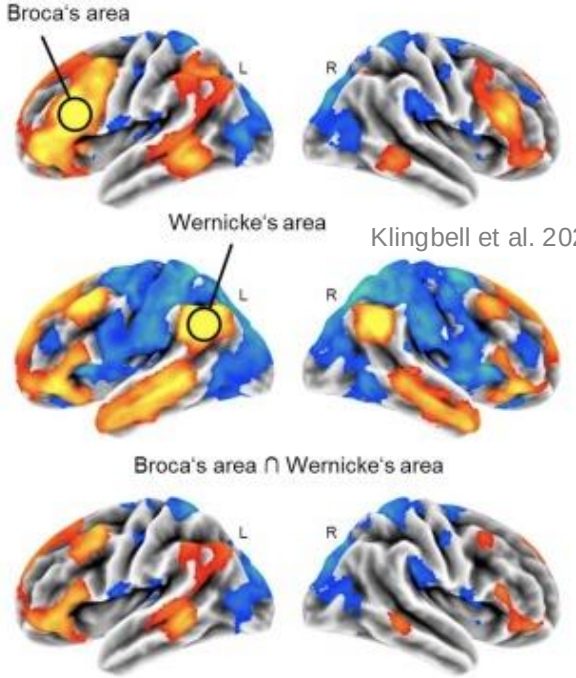
VanEssen et al. 2019



Correlation matrix

Resting state (rs-fMRI)

Seed-based functional connectivity



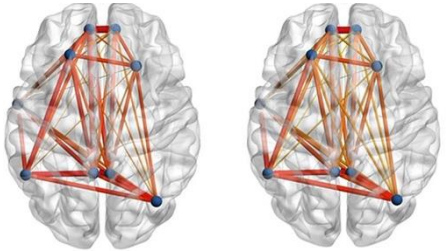
Klingbell et al. 2029

Revealing „functionally connected“ regions
Take the signal of one „seed“ voxel or region, and correlate with the one of all other voxels

Parcellation based on brain-wide „connectivity fingerprints“

Grouping voxels with similar connectivity

Network-level perspective on mental processes



Fernandez et al. 2022

Eyes open Eyes closed

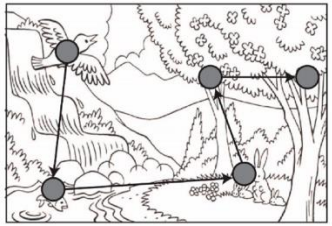
Comparing connectivity estimates across conditions

Resting state (rs-fMRI)

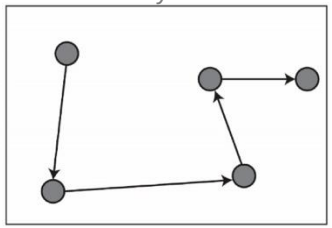
Important: Behavioral tracking is essential for task-based AND task-free approaches!

Example 1: “Looking at nothing“ effect

Wynn et al. 2017



„Look at this picture“

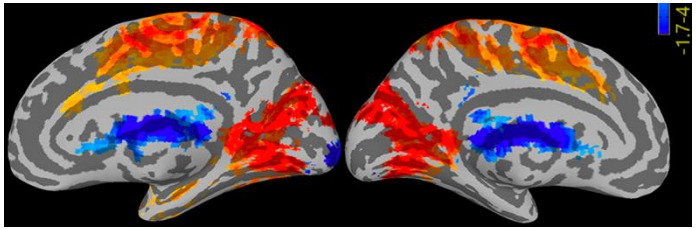


„Think of the picture“

Technically a task here, but this likely happens during rest too!

Example 2: Eye movements predict activity during rest

Koba et al. 2021



Extensive discussion on tasks and behavioral tracking here:

Perspective | Published: 29 July 2024

Centering cognitive neuroscience on task demands and generalization

Matthias Nau, Alexandra C. Schmid, Simon M. Kaplan, Chris I. Baker & Dwight J. Kravitz

Nature Neuroscience **27**, 1656–1667 (2024) | Cite this article

Resting state (rs-fMRI)

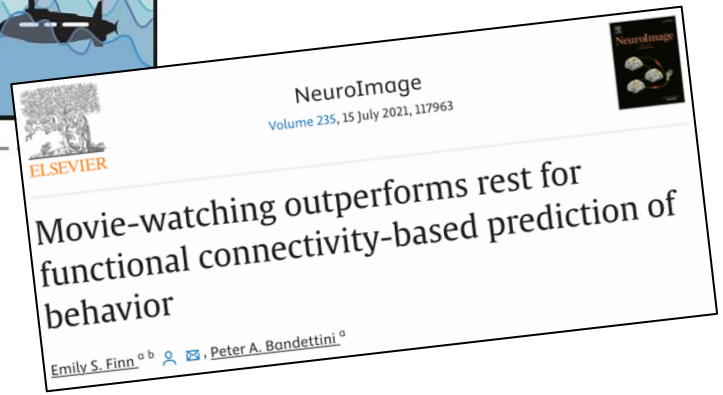
Why study rest?

- **Easy to perform** (e.g., no task equipment required).
- **Widely applicable** in special populations (e.g., patient groups, elderly, children).
- Task-evoked responses often explain shockingly little variance (<5% of total signal).
- Fertile ground for the development of **data-driven analysis tools.**

Common criticism

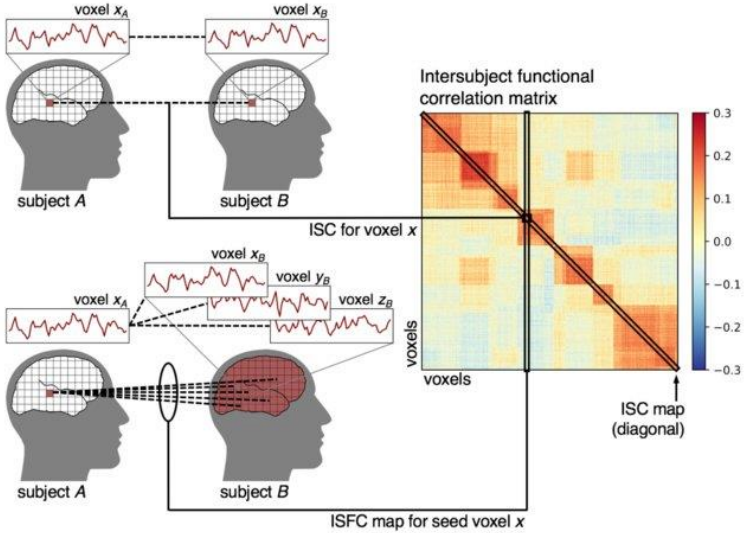
- **No control or measurement** of what participants experience or do.
- Often **difficult interpretation** of results.
- **Imaging artifacts** (e.g., caused by motion) strongly affect connectivity results.
- Functional connectivity does NOT reflect **anatomical connectivity.**
- Resting state results are **not very predictive** of behavior.


Integrated
approaches


NeuroImage
Volume 235, 15 July 2021, 117963
ELSEVIER
Movie-watching outperforms rest for functional connectivity-based prediction of behavior
Emily S. Finn
Peter A. Bandettini

Task-based paradigms with data-driven (rest-inspired) analyses

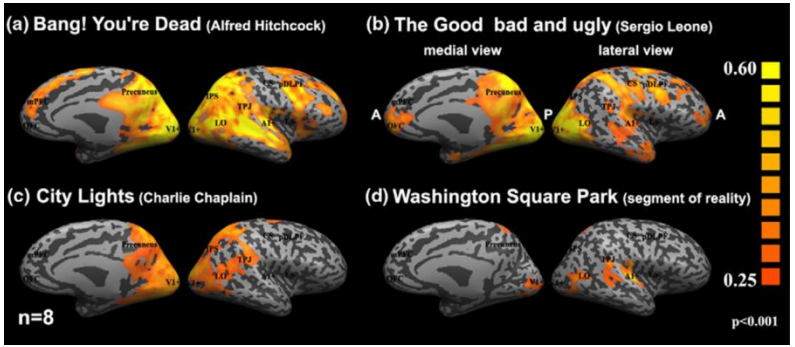
Example: Inter-subject correlation (ISC)



Correlate voxel time courses <u>across participants</u>, unlike (within-participant) functional connectivity

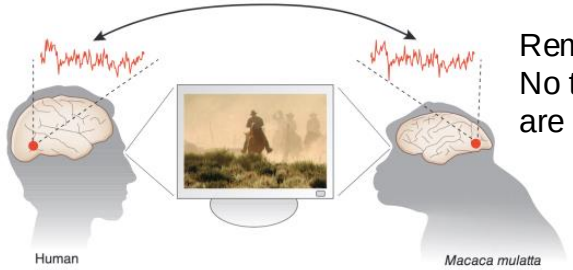
Reveals brain activity that is shared across people, illuminating «general principles»

ISC during movie watching



There are many variants of the ISC idea out there (e.g., hyperalignment, Haxby et al. 2020)

Example: Inter-species correlation



Remember though: No two brains are the same!

General take-aways

- Your **research question** decides which experimental approach is optimal for you
- Task-based approaches offer **control** and better **interpretability**, whereas resting state can be great for **data-driven exploration** (or integrated paradigms)
- Experiments often **trade-off** experimental control and ecological validity
- When you **give up control**, you need to **measure more**!
- Task design and analysis go hand in hand – **Think about analyses** when designing tasks
- **Behavioral tracking** can help interpret data acquired under any and all tasks

Key terms to remember

- Task-based paradigms
- Task-free paradigms (i.e. Rest)
- Integrated paradigms
- Block designs
- Event-related designs
- Behavioral tracking
- Experimental control
- Naturalistic conditions
- Ecological validity
- Resting state
- Functional connectivity
- Activity covariation
- Anatomical connectivity
- Default mode network
- Seed-based connectivity
- Inter-subject correlation

Image: amberusa.com

That’s a wrap. Have fun!