Neural mechanisms in processing of Emotion in Real and Virtual faces

Using functional-near infrared spectroscopy (fNIRS)

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July 9, 2025

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ADSL


- Our brains are evolutionarily primed to process faces, as they are crucial for social interactions.
- A central aspect of facial perception is emotional expressions, which underpins our interactions as social beings.
- It is currently unclear how the brain processes emotional expressions, despite much research. [2]
- Early models of facial perception proposed modular processing: face identity was linked to the fusiform face area (FFA) [2], while emotional expressions were associated with limbic structures like the amygdala. [4]

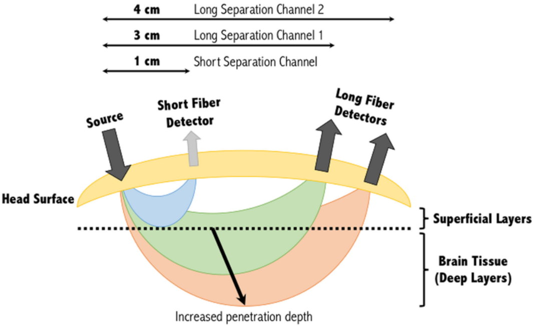
- As humans spend increasing time in digital and virtual environments, we interact more and more with computer-generated/avatar faces in our lives.
- While real-face emotion processing has been studied extensively, the neural mechanisms for perceiving and responding to virtual faces remain poorly understood. [1]
- Recent evidence suggests face and emotion processing recruit distributed brain networks rather than isolated "face areas," pointing to a need for network-level investigation. [3]

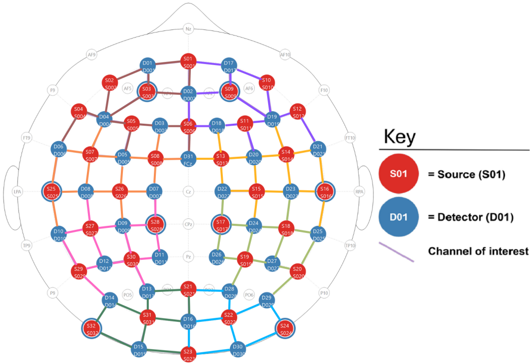
- **Objective:** Identify distinct patterns of brain activity that represent processing of different emotions on real and virtual faces.
- **Hypotheses:**
  1. H_1: Differential activity between real and virtual faces.
  2. H_2: Differential activity across different emotions (anger, disgust, fear, happiness, sadness, surprise, neutral).

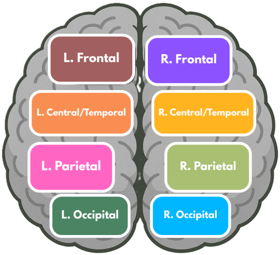
Methodology
Participants

- Participants were recruited from the Ontario Tech University SONA system and were compensated with course credit.
- 87 participants completed the experiment, but only 52 participants were included after excluding those with poor data quality.
- We used thresholds common in fNIRS research such as the Scalp Coupling Index (SCI) to determine the quality of the data.
- The 52 participants ranged in age from 17-51 years old, with a mean age of 22 years, and 39/52 were female.

- **Functional near-infrared spectroscopy (fNIRS)** is a non-invasive tool that tracks changes in blood oxygen levels in the brain as an indirect measure of neural activity.

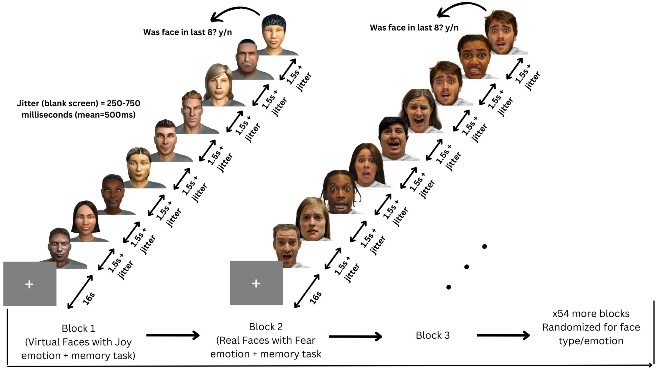






- Montage of fNIRS cap, which shows the placement of the optodes on the scalp.
- Each neighboring pair of source (red) and detector (blue) optode is referred to as a channel (purple line), resulting in 103 channels.

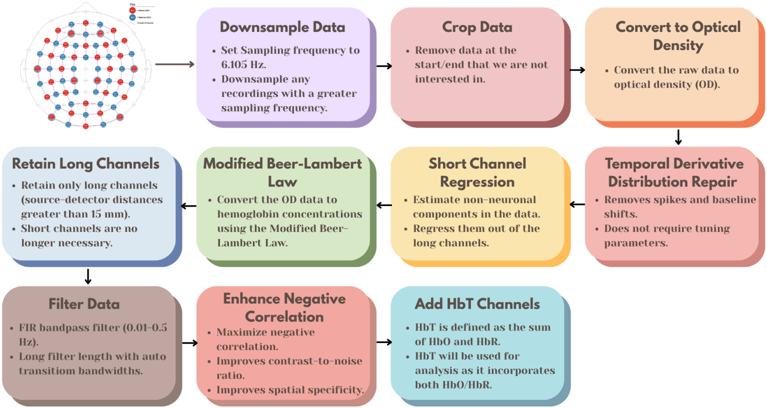
Methodology
Design and Procedure



- Participants viewed 56 blocks of 8 faces, each block being either all real or all virtual faces.
- Every face in a block displayed the same emotional expression, one of: anger, disgust, fear, happiness, sadness, surprise, neutral.
- **Memory task:** Participants had to indicate whether the 9th face was present in the previous 8 faces by answering "yes" or "no".

Analyses

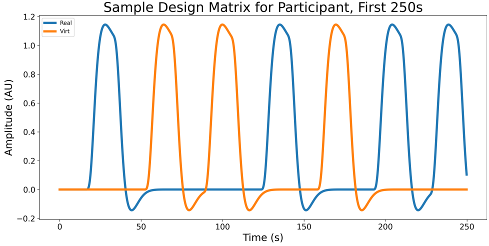
Preprocessing Steps



- Prepare raw fNIRS data for analysis by removing noise, artifacts, and irrelevant information.
- This ensures the data is suitable for extracting meaningful insights about brain activity.

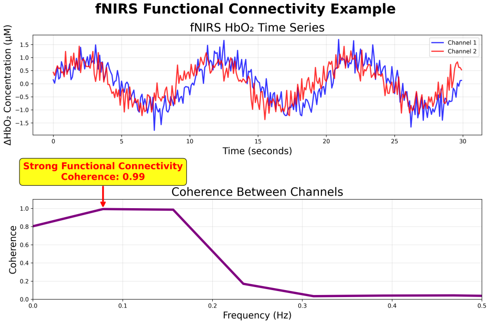
General Linear Model (GLM):

- Create a design matrix where each column represents one type of event/condition.
- For each stimulus column, you mark onset/offset times and then "stretch" those into the shape of a typical blood-flow response.
- This gives you a set of predicted response patterns for each condition, that you'll try to match to your actual fNIRS recordings.



- We then find a set of β-values (using OLS), that tell you how big the brain's blood-flow response was for each event type.
- A higher β-weight means a stronger activation associated with that stimulus in that channel.

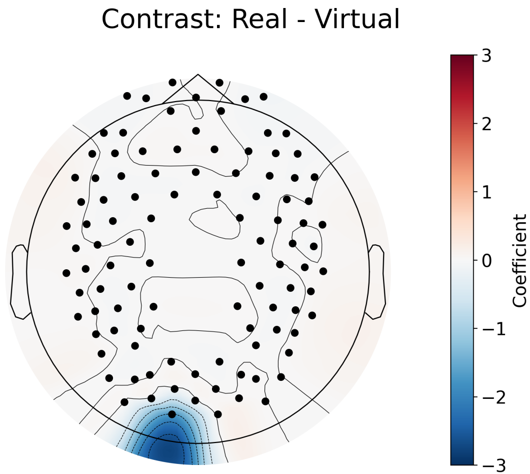
- **Functional connectivity (FC)** describes how blood-flow signals from different brain regions fluctuate together over time, showing which areas of the brain are working in sync.



- We apply a continuous wavelet transform (CWT) using a Morlet wavelet focused on the 0.2-0.5 Hz band.
- The CWT gives us coherence scores (ranging from 0 to 1) for frequencies within that band.
- In summary, by looking at how similar these averaged coherence values are between every pair of regions over time, we can see which brain areas synchronize their activity under different conditions.

Results

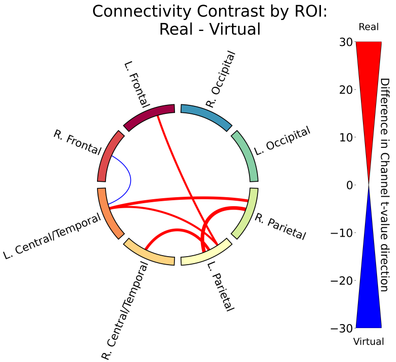
Real vs. Virtual Faces



- GLM contrast for Real vs. Virtual Faces.
- Left Occipital region has slightly more activation for Virtual Faces.

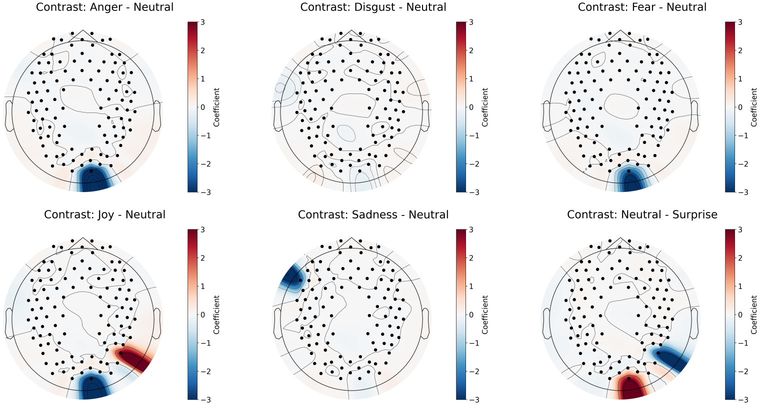
Results

Real vs. Virtual Faces



- Significant differences in connectivity between regions for Real vs. Virtual Faces.
- We see most differences in connectivity between Left Frontal-Left Parietal and Left Prefrontal-Right Occipital regions.

Neutral vs. All Other Emotions

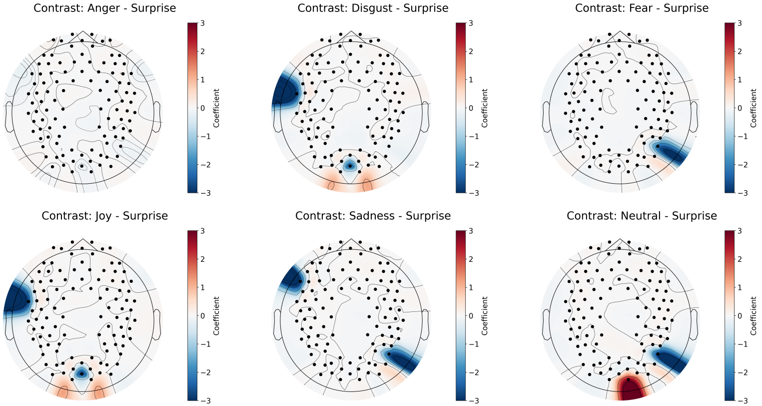


- The GLM contrast for Neutral vs. all other emotions shows differences in activation in multiple regions. (except disgust)

Results

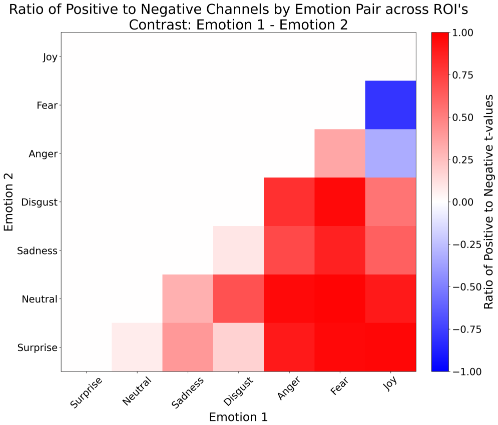
Emotional Faces

Surprise vs. All Other Emotions



- Surprisingly, the GLM contrast for Surprise vs. all other emotions shows differences in activation in multiple regions. (except anger)
- **No other pairs of emotions showed significant differences.**

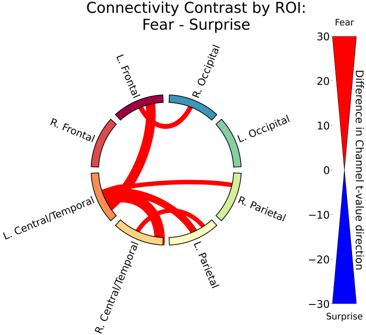
Results
Emotional Faces

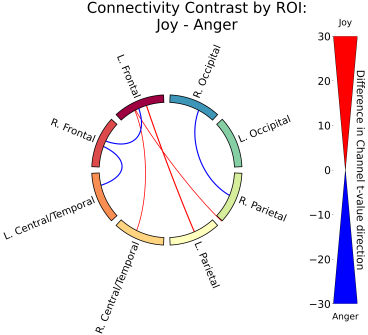


- Count of significantly different channel pairs by emotion.
- We see the largest differences in absolute connectivity levels for the Fear-Surprise pair, and more similarities in connectivity for the Joy-Anger pair.

Results

Emotional Faces

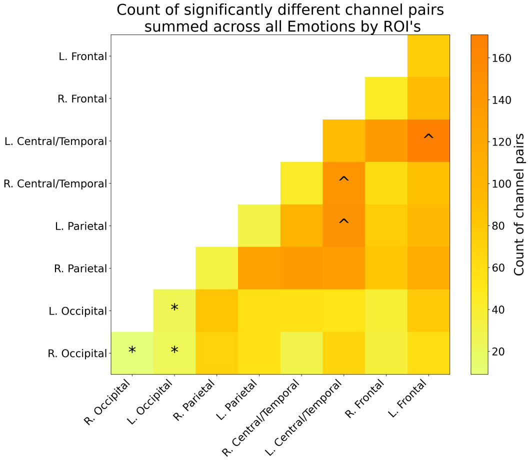




- Significant differences in connectivity between regions for Fear-Surprise (left) and Joy-Anger (right).
- Both pairs of emotions show less differences in the occipital regions (left occipital and right occipital) and between themselves (Left and left occipital and right and right occipital).

Results

Emotional Faces



- Count of significantly different channel pairs by region.
- The 3 regions with the most similarities/differences in connectivity are marked with asterisks/carets respectively.

Real vs. Virtual Faces:

- H_1: Differential activity between real and virtual faces.
  - There is increased left occipital activation for virtual faces, compared to real faces.
  - There are significant differences in connectivity between:
    - Left Frontal-Left Parietal regions
    - Left Prefrontal-Right Occipital regions
  - These regions indicate real and virtual faces are processed differently—more so than GLM results suggest.

Emotional Faces:

- H_2: Differential activity across different emotions (anger, disgust, fear, happiness, sadness, surprise, neutral).
  - Surprise and Neutral show higher activation in multiple regions compared to all other emotions.
  - The other emotions did not show significant differences in activation between each other.
  - Left occipital and right occipital regions show the most similarities in connectivity, suggesting they are more synchronized with each other than any other pair of regions, regardless of the emotion.

Conclusion

- **Implications:**
  - Offers insight into how the brain responds to virtual stimuli, relevant for Virtual Reality (VR), Brain Computer Interfaces (BCI).
  - Can inform the design of more realistic and effective virtual characters in education and/or gaming.
- **Future Research:**
  - Future research could explore how these neural differences influence real-world behaviors, or how they affect interactions in digital environments.

References I

[1] Aline W. De Borst and Beatrice De Gelder. Is it the real deal? Perception of virtual characters versus humans: an affective cognitive neuroscience perspective. *Frontiers in Psychology*, 6, May 2015. ISSN 1664-1078. doi: 10.3389/fpsyg.2015.00576. URL `http://www.frontiersin.org/Cognitive_Science/10.3389/fpsyg.2015.00576/abstract`.

[2] Hiroto Kawasaki, Naotsugu Tsuchiya, Christopher K. Kovach, Kirill V. Nourski, Hiroyuki Oya, Matthew A. Howard, and Ralph Adolphs. Processing of Facial Emotion in the Human Fusiform Gyrus. *Journal of cognitive neuroscience*, 24(6):1358–1370, June 2012. ISSN 0898-929X. doi: 10.1162/jocn_a_00175. URL `https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3566877/`.

[3] Kristen A. Lindquist, Tor D. Wager, Hedy Kober, Eliza Bliss-Moreau, and Lisa Feldman Barrett. The brain basis of emotion: A meta-analytic review. *Behavioral and Brain Sciences*, 35(3):121–143, June 2012. ISSN 1469-1825, 0140-525X. doi: 10.1017/S0140525X11000446. URL `https://www.cambridge.org/core/journals/behavioral-and-brain-sciences/article/brain-basis-of-emotion-a-metaanalytic-review/80F95F093305C76BA2C66BBA48D4BC8A`.

References II

[4] Wataru Sato, Sakiko Yoshikawa, Takanori Kochiyama, and Michikazu Matsumura. The amygdala processes the emotional significance of facial expressions: an fMRI investigation using the interaction between expression and face direction. *NeuroImage*, 22(2):1006–1013, June 2004. ISSN 1053-8119. doi: 10.1016/j.neuroimage.2004.02.030. URL https://www.sciencedirect.com/science/article/pii/S1053811904001235.